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AN ECONOMIC ANALYSIS OF NITROGEN REDUCTION IN SUBSURFACE DRAINAGE WATER

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CALIFORNIA AGRICULTURAL EXPERIMENT STATION
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TABLE OF CONTENTS

Page

INTRODUCTION 1

Federal and State Water Resource Development 2

The San Luis Drain 4

The Problem 6

FRAMEWORK OF ANALYSIS 9

Multiperiod Linear Programming Model of the Westlands Water District 18

Objective function 22
Reclamation activities 35
Water purchasing activities 36
Nitrogen fertilizer purchasing activity 36
Wastewater treatment activities 36
Soil constraints 38
Water constraints 38
Market constraints 38
Water requirements 42
NO_3-N in drainage water 42

EMPIRICAL RESULTS 50

NO_3-N Charge and Treatment Alternatives 50

Allocating NO_3-N Removal Costs to the Public Sector 56

Allocating NO_3-N Removal Costs to District Landowners by Increasing Project Water Costs 57

Land and Water Use 58

Cost of Achieving Alternative Levels of Water Quality 60

Costs of nitrogen abatement 60
The damages of nitrogen pollution 62

TABLE OF CONTENTS

Page

CONCLUSIONS 66

Suggestions for Further Research 68

APPENDIX A 69

APPENDIX B 73

APPENDIX C 75

APPENDIX D 86

REFERENCES 88

SUMMARY

The cost of achieving a 2 ppm nitrate-nitrogen (NO_3-N) standard on irrigation subsurface drainage water was estimated for three pollution control policies. A policy of public responsibility for removing the nitrogen was compared with two policies that internalized the responsibility to irrigators. One internalization policy analyzed is an effluent charge where irrigators are taxed on the amount of NO_3-N in their drainage water. Another internalization policy is the use of a treatment system and charging irrigators according to the cost of physically removing NO_3-N from their drainage water.

The cost of the NO_3-N charge system to achieve the standard was estimated to be about 70 percent less than having the public responsible for achieving the standard and about 5 percent less than the treatment system. Under the system of public responsibility, a treatment plant would be required to achieve the standard at an annual cost of \$1.86 million compared to \$1.36 million if these costs were allocated to irrigators. The NO_3-N charge alternative could achieve the standard at an average total cost of \$525,000 of which \$451,000 is reduced annual income caused by production adjustments and \$74,000 is collected by the District in charges. The cost of achieving the standard under the NO_3-N charge alternative is \$0.95 per acre of District land and \$2.77 per acre under the treatment alternative.

The amount of drainage water decreased substantially under both policies of internalization. This decrease is chiefly the result of reduction in drained land under production, rather than the amount of drainage water per acre. Also, crops were placed on soils that minimize the leaching of natural nitrogen from the soil. And while less fertilizer was utilized, lower fertilizer rates than required for maximum yields did not appear in the optimal linear programming

solution to achieve any of the quality standards. This implies that a nitrogen water quality standard on drainage water can be achieved at lower cost by changing cropping patterns and land use rather than by decreasing nitrogen fertilizer rates on existing cropping patterns. Thus, the hypothesis that the NO_3-N charge system would achieve the water quality standard at the lowest possible cost is substantiated.

The amount of idle land is substantial with or without the imposition of a quality standard on drainage water. The total amount of District land available at full development for irrigation is about 553,000 acres. Without a standard, about 386,000 acres will eventually be in production. None of the lower productivity soils will be in production due to a high water table and the lack of profitable crops adaptable to these low productivity soils. Crops that were profitable prior to a high water table will not cover the costs of installation and operation of a subsurface tile drainage system. Under the NO_3-N charge system, about 360,000 acres of land will be in production.

The costs of implementation, enforcement and acquiring information relative to a given policy were not estimated in this study. These costs could possibly exceed the net social benefit of the nitrogen pollution control policy. Therefore, these costs should be estimated and compared for the policies analyzed in this study.

AN ECONOMIC ANALYSIS OF NITROGEN REDUCTION IN SUBSURFACE DRAINAGE WATER

by

Gerald L. Horner*

INTRODUCTION

Rapid development of California has provided impetus for planning massive water development programs in the State. Historically, severe water shortages in the Central Valley and southern parts of the State contrasted with plentiful supplies in the northern areas. This situation suggested the possibility of damming northern rivers to provide flood control, stream level control, outdoor recreation opportunities to northern residents and transporting excess water via canals to deficient areas. The plan was technically feasible and had strong appeal to the populous arid regions. Since the goal of development has always been highly regarded by a certain segment of society, considerable resources have been allocated to public financing and construction of interbasin water transfers in California.

Intensified agricultural production using the additional water has greatly increased the problem of wastewater disposal. Irrigation return flows were projected to contain sufficient nitrate-nitrogen (NO_3-N) to cause an environmental hazard and the Environmental Protection Agency proposed a quality standard on its disposal (Central Pacific Basins Comprehensive Water Pollution Control Project, 1967). Although a quality standard on return flows has not been formally established, the proposed disposal requirement is recognized and the economic impact of the results will depend on the method utilized to achieve the proposed standard.

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The objectives of this study are:

1. To compare the social and private costs (reduced production and incomes, increased production costs or treatment costs) of achieving a return flow standard under alternative policies of:
    a. allocating the costs to the public sector,
    b. recovering the costs by an effluent charge on the individual irrigators, and
    c. recovering the costs by increasing the price of irrigation water.
2. To project the level of agricultural commodities produced and the level of resource use under each policy.
3. To determine the economic costs of allowing alternative quantities of NO_3-N in drainage water.

A multiperiod linear programming model based on an infinite planning horizon was utilized to derive a set of cropping patterns to maximize the present value of all future returns to land and management, subject to the supply of resources and the restrictions on drainage water disposal. The model was structured to include four alternative fertilizer levels for 18 crops and six soil types to determine the quantity of nitrogen content of the drainage water resulting from a given cropping pattern. This configuration of the model permitted changes in the quantity of nitrogen fertilizer applications and the land utilization by soil types in response to alternative policies on drainage disposal. Farmers in the district are able to choose between paying the cost of drainage water disposal or changing or curtailing production practices that produce nitrogen in the drainage water. The optimal or least cost policy could involve one or a combination of these outcomes.

Federal and State Water Resource Development

In 1935, the Federal Government authorized the Central Valley Project. By 1990, delivery is projected to approximate 10.7 million acre-feet of water, most of which will be utilized for irrigation. The planned cost of present and authorized project facilities is estimated at about $2.6 billion. Presently, the project delivers approximately 6 million acre-feet of water. In addition, the State of California initiated the State Water Plan in 1951 to provide flood control and to transport about 4 million acre-feet of water from Northern to Central and Southern California via a complex system of canals, pumps, and dams. The planned cost of the State Water Plan is estimated at approximately $2.8 billion [California Department of Water Resources, 1970].

The Westlands Water District was formed in 1952 by the San Joaquin Valley West Side Landowners Association for the explicit purpose of securing a Federal water supply to supplement the area's diminishing ground water table. The District, composed of 378,000 acres and later increased to 592,093 acres, is located in Fresno and Kings Counties. In 1955, in response to a District request, the Bureau of Reclamation proposed the San Luis Unit of the Central Valley Project as a Federal reclamation project and in 1960 the U.S. Congress authorized construction.

The San Luis Unit included participation by the State of California and featured three major facilities (1) the San Luis Dam with a 2.1 million acre-feet capacity reservoir, (2) the California Aqueduct from Dos Amigos pumping plant to Kettleman City and (3) two smaller detention reservoirs (34,562 and 13,236 acre-feet capacities). The project will cost an estimated $623 million with the State contributing $163 million and the Federal Government contribution of $460 million in the form of an interest free loan. Water is pumped from the Sacramento-San Joaquin River Delta to the San Luis Reservoir during the winter and released during the summer to the California Aqueduct (State) for distribution to the Westlands Water District, 12 California irrigation districts and Southern California.

In 1965, the Westlands Water District contained about 428,000 acres of irrigated land that depended on 900,000 acre-feet of water from existing ground water supplies. Delivery of Federal water from the San Luis Project began in 1968 and will increase to a maximum of about 1.09 million acre-feet in 1979 [De Bruyn, 1971].

The population of the District is about 7,500 persons with very few incorporated communities. The sparse population can be attributed mostly to the land ownership patterns and the lack of prior economic activity. The Bureau of Reclamation estimated in 1968 that 202,553 acres, or about 34 percent of the land in the District, was owned by 18 corporations or individuals out of a total of 2,492 landowners. The District is subject to the Federal law which limits water deliveries from a Federal project to 160 acres for any individual owner. In 1968, there were 345 persons or corporations holding contracts for delivery of Federal water who have land in excess of the 160 acre limitation. These individuals all had signed recordable contracts to dispose of excess lands.

Financing for the construction of the District's distribution and drainage systems is part of the San Luis Unit project, the total cost of these facilities is estimated to be about $160 million.

The San Luis Drain

The San Joaquin Valley is divided into two hydrological basins, the San Joaquin and the Tulare. The San Joaquin Basin is the northern part of the San Joaquin Valley and is drained by the San Joaquin River and three main tributaries: the Merced, Tuolumne and Stanislaus Rivers. The rivers originate in the Sierra Nevada mountains and provide water for irrigation, ground water recharge, municipal use and the dilution of effluents. The San Joaquin River discharges into the Sacramento-San Joaquin Delta which eventually flows into the Pacific Ocean via the Suisun-San Pablo and San Francisco Bays.

The Westlands Water District is located on the west slope of the Tulare Basin which comprises the southern half of the San Joaquin Valley. The Basin is essentially closed or not externally drained, and water entering the Basin collects in Tulare Lake where it evaporates or enters underground aquifers. The projected deliveries of 1.09 million acre-feet of water to the Westlands plus 3.8 million acre-feet to other districts in the Tulare Basin by 2020 present a formidable drainage problem.

Irrigation water in California normally has between 50 and 1,500 parts per million (ppm) of dissolved salts. The dissolved salts from the water tend to accumulate in the root zone because they are not consumed by the irrigated plants. The build-up of dissolved salts in the root zone can create a condition adverse to plant growth. Application of water in excess of plant requirements will leach some of the salt build-up into lower soil profiles. When the amounts of salts entering and leaving the root zone are equal, a salt balance is said to be established. However, since the Tulare Basin lacks a drainage outlet, salts that are imported in irrigation water will accumulate in the Basin. In areas of the Basin where soil permeability is low, increasingly saline water tables are rising into the root zone and restricting crops to the most salt tolerant which also happen to be the lower value crops. Economic feasibility of crop production and the capacity to repay water costs of the District are based on cropping patterns requiring well drained non-saline soils. Since about 300,000 acres of Westlands Water District will eventually require drainage [California Dept. of Water Resources, 1969], an export drain system was included in the original 1954 feasibility report.

The State Department of Water Resources concluded that about one million acres of irrigated land in the San Joaquin Valley might require drainage by

2020. In consideration of this information, the State Burns-Porter Act of 1960 "authorized" such a drain for the State Water Project while the 1960 Federal legislation required that a drain be constructed for the San Luis Project either by Federal or State agencies. Since the State could not insure their share of construction of a drain to serve both the Federal and State projects in the Valley, the Bureau of Reclamation is currently constructing a drain to convey the subsurface drainage water from the Westlands Water District's 300,000 acres that will eventually require drainage.

The San Luis Drain, will originate at Kettleman City and eventually terminate near Antioch in the San Joaquin-Sacramento River Delta, a distance of 188 miles. A completion date of July 1977 is projected by the Bureau of Reclamation. The originating capacity of the drain will be 50 cubic feet per second (cfs) and expand to 450 cfs at the point of discharge.

The Problem

In 1963, a drainage plan was devised by the California Department of Water Resources and the U.S. Bureau of Reclamation for the San Joaquin Valley of California. The plan included a joint drain to serve the projected State and Federal irrigation project needs. The drain known as the San Joaquin Master Drain, was to be 280 miles in length with an originating capacity of 60 cfs and 90 cfs capacity at the terminus. However, the State failed to secure the necessary repayment potential and the Federal San Luis Drain was constructed. The State is presently reconsidering the Master Drain. The Master Drain was to follow the same route as the present San Luis Drain, but would have extended further south into Kern County. To minimize construction costs, a discharge point to the San Joaquin River near the City of Antioch was chosen. Disposal of a projected 500,000 acre-feet of waste water in the Delta and San Francisco Bay by the year 2000 raised questions about the effects on the general water quality in the San Francisco Bay. Public concern was manifested in the 1965 formulation of the Central Pacific Basin's Comprehensive Water Pollution Control Project of the then Federal Water Pollution Control Administration (under the Environmental Quality Act of 1970, the Environmental Protection Agency absorbed the FWPCA). The FWPCA project was charged with a complete investigation of the effects of the San Joaquin Master Drain on the receiving waters of the Delta and San Francisco Bay.

The following is a summary of the conclusions of that investigation [Central Pacific Basins Comprehensive Water Pollution Control Project, 1967]:

1. The discharge of the San Joaquin Master Drain into the San Joaquin River at Antioch would have detrimental effects on the water quality of the Delta and San Francisco Bay. Nitrogen content of the waste water would be sufficient to allow growth of large quantities of algae and aquatic plants.
2. The economic loss due to eutrophication of receiving waters was estimated at about $11 million annually. Economic losses included projected fishery losses and increased costs of using the water for recreation, boating, navigation, industrial cooling and other purposes.
3. The problem could be eliminated by reducing the amount of nitrogen in the waste water to 2 ppm of NO_3-N by a treatment method.
4. The excess nutrient problem could not be solved by increasing the Delta flow and diluting the waste water.
5. The salinity of the waste water would not be detrimental as long as a 3,000 cfs Delta outflow was maintained.

The study also recommended the following:

1. That the Office of Saline Water, FWPCA, the California DWR and the Bureau of Reclamation jointly investigate the economic feasibility of removing nitrate nitrogen from the water of the San Joaquin Master Drain. The removal technique should insure that the receiving waters would meet a 2 ppm NO_3-N standard. This group was called the Agricultural Wastewater Study Group (AWSG).
2. That the alternative of conveying the drainage water to the ocean for disposal should be compared to treatment.
3. That the characteristics of subsurface tile drainage be the subject of a detailed analysis by the aforementioned research unit.
4. That a monitoring system be established to record the quality characteristics of the possible receiving and drain water.

The conclusions most important to the Westlands project were the effluent standard of 2 ppm of NO_3-N to be placed on drainage water delivered by the San Luis Drain to the Delta, and the establishment of a research group to determine the economic and physical feasibility of removing nitrate nitrogen from the drainage water. Several important research conclusions made by this latter group will be discussed in more detail later in this report. One conclusion of particular importance, however, grew out of a survey of the current drainage operation in the area to be drained by the San Luis Drain, which showed that the probable resulting drainage effluent would contain at least 20 ppm of NO_3-N [California Department of Water Resources, 1969]. This meant that extensive treatment would have to be implemented at considerable cost. The AWSG estimated costs of the least cost technique at about $30 (1970) per acre-foot of drainage water. Projected acreage to be drained in the Westlands Water District by the year 2000 was about 300,000 acres. At an average drainage coefficient of .5 acre-feet per acre, a total of 150,000 acre-feet of drainage water will require treatment.

On-farm drainage costs will affect the kind of crops produced and aggregate production from the District. If treatment costs are also imposed, they can be paid for in several ways. This study will investigate various methods of allocating those costs to producing units in the District that would affect resource use, returns to factors of production, the amount of agricultural production and the economic viability of the entire project over time.

FRAMEWORK OF ANALYSIS

Theoretically, the result of a decentralized decision-making economy is a maximum welfare solution where the correct amount and kind of goods and services desired by consumers are produced by the cheapest possible method. This occurs only when the markets are competitive, consumers and producers maximize their well-being, the distribution of income is judged to be acceptable, and there is complete independence with regard to the actions of consumers and producers.

To consider this set of restrictive assumptions as being realistic in today's economy is naive but its use is not without merit. The competitive model can be used to illustrate the effects of failures within the model and offer implications for policy action to correct inadequacies. A common market failure in today's developed economy occurs when the actions of some producers and consumers affect the level of production or consumption of other persons in the economy. The market does not provide the affected party a method of communicating to the offending party the amount of good or harm his particular action is causing. The market system is expected to relay this kind of message automatically. If a new and desirable product is produced by a firm and traded in an organized market, consumers' desire to increase their total utility will lead some of them to purchase the new good at the expense of some goods they formerly purchased. The price of the goods formerly purchased will be depressed and the price of the new good increased. The changing prices will prompt the respective firms to change production levels to improve efficiency and to again maximize profit. However, if the new good does not enter an organized market, and therefore does not have a price, an inefficient or nonoptimal situation will exist.

Pigou [1937] recognized that when an economy matures and becomes more interdependent, externalities may cause enough distortion that society would clearly benefit from making firms take account of their actions. Economists have written extensively on the attributes of various methods of internalizing externalities. The legal process, the market solution and systems of charges, subsidies and standards are institutional devices generally recognized as viable in solving problems of externalities. The legal process has not been too successful in generating long term solutions in externality problems largely because of the time lag between filing a suit and a court decision [Kneese and Bower, 1968]. Other problems, such as the uncertainty of the kind of decision that may be rendered and the fact that most pollution damages are widely dispersed over a broad area or among a large number of persons, make organizing to file a suit difficult. Even if courts could overcome such problems, efficient solutions probably would not result from court settlement because most persons damaged by the externality would claim the full amount of damages against a polluter. The conditions for efficiency developed above state that each firm must take into account those costs imposed on other economic units. Social damages due to externalities are defined as the net production lost to society and not the gross individual damages that, in some respects, seem justified.[2] Consider, for example, the firm that has an annual payroll of $100,000 in a fishing operation, with negligible capital investment (for the sake of simplification), with variable costs, a labor supply that can be employed in the same region with no loss in wages and with a profit of $10,000 per year. If an upstream plant discharges enough waste into the river to kill the fish, the actual social damages would be $10,000 instead of $110,000, the market value of the fish. This example assumes that the fish have no other value to society and that the degraded water affects no one else. Since the labor could immediately be otherwise employed, society would lose only the difference between the value of the fish lost and the value of the replaced resources in their alternative employment. In a legal settlement, this value would be determined in an arbitrary manner.

The market solution has received support from some economists. Coase [1960] concluded that the market system would internalize all externalities through negotiations. However, market solutions require an institutional framework in which the party creating social damages and the damaged party can bargain to achieve some mutually optimal level of damage. First, a system of property rights or liability rules has to be established to provide an incentive for bargaining and, therefore, the rights must be transferable. One liability rule could establish the right of the polluter to dump his wastes into the river which would give the fishing firm the incentive to pay the firm to withhold wastes (zero liability rule). The opposite rule (full liability rule) would be to give the fishing firm the right to an unpolluted fishing area. The upstream firm would then want to bribe the fisherman to let him use the river for some level of waste disposal. Such negotiations would increase the combined total profits of the two firms no matter which liability rule was in effect.[3/]

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[2] See Kneese and Bower, pp. 82-88.

Assume the upstream manufacturing firm has been granted the right to use the river for waste disposal and may either release its wastes directly into the river to treat them prior to release. Since the river represents a free resource in which to dispose of the wastes, the choice of action will certainly be to release the wastes without treatment.

The fisherman could bribe the upstream firm into treating an amount of waste that would equate the amount of the bribe per unit of waste and the marginal amount of profits the fisherman could realize by the upstream firm withholding another unit of waste. When the liability rules are reversed and the fisherman is given the right to keep the fishery in its natural state, the upstream firm will pay the fisherman for the right to dispose of wastes. The firm will minimize its total waste disposal cost which consists of treatment costs and payments to the fisherman for permission to use the river for disposal.

The market approach does not carry the same appeal to government environmental agencies as it does to economists for good reason. Establishing organized markets that would transmit close approximations of damages and costs among many firms and affected persons might very well cost (transactions costs) more than the loss in productivity as a result of the externalities.

[3/] This assumes that no consumers will be affected, capital is a free good and the costs of negotiations are negligible. If these assumptions do not hold, the zero liability rule will result in more pollution and more goods produced at lower prices [Randall, 1972].

Systems of effluent charges, subsidies or effluent standards are available to governments to make firms realize the costs they are imposing on society and to improve the aggregate welfare. Implementation of these devices requires a public agency with the authority and the objective to maximize the society's benefit from the particular resource.

Theoretically, an efficient allocation of resources can be achieved either by charging the polluter the amount of social damages he causes or by paying a subsidy to the polluter if he curtails his waste disposing activity. The charge and/or subsidy system is similar to the market solution except that the government has dictated the solution (the amount of payment), thereby avoiding the transactions costs of the market.

There are, of course, many other differences between the two systems. First, the distribution of income resulting from the two systems would be different. Second, the administrative problems presented by the payments system almost excludes the possibility of use. One of the information requirements would be the quantity of waste discharge for a firm maximizing profits. This may be impossible to determine as there would be an incentive for the firm to overestimate its normal waste output. Also, payments would have to continue after a plant curtailed production since rescinding the payment might induce the plant to reestablish the previous level of production and externalities.

If a Pareto optimal charge or payment is to be levied on the firm, a damage function must be estimated for a given amount of waste discharged to a particular body of water. The estimation of the function is difficult because nonmarket goods such as outdoor recreation or the esthetic qualities of water cannot be quantified in money terms. Any dollar value assigned to many of these goods is subjective and is unlikely to be accepted by all parties concerned, especially the firm or firms being charged.

Estimating damages to firms other than the one discharging waste also presents some formidable problems. If a number of firms use a common river for waste disposal, damages may not be a linear function of any one firm's waste discharge but a function of the amount of wastes several firms discharge. Knowledge of such interrelationships is necessary before charges can be established to achieve an optimal amount of reduction in damages. Examples of these types of functions are: (1) where damage is not a linear function of the amount of wastes in the river, and (2) where a particular waste discharged by one firm mixes with another waste from a second firm to create yet a third damage substance. The complexity of the problem increases rapidly with the addition of more firms and wastes exhibiting interdependent marginal social cost characteristics.

The total of damages caused by a given amount of wastes deposited in a river is also a function of their dilution and temperature. This requires an estimate of the temperature and amount of water in the river at a given time, expressed as a probability. The damages then become a function of the probabilistic characteristics of the environment, which can be estimated for most bodies of water utilizing current statistical techniques. The expected value of damages is then a function of the level of waste discharge and the probabilistic characteristics of the natural environment.

Other problems of estimating damage functions arise in considering the differences between short-run and long-run external costs. Changes which are

Pareto optimal in the short run could change water quality enough that a new activity would be attracted to the area. In such cases, provisions should be made to estimate the long-run benefits of withholding wastes and to include them in the calculation of the effluent charge system.

Water quality standards are established for particular bodies of water by public agencies because standards minimize administrative problems. A standard represents a minimal level of water quality that will be required and provides that firms responsible for quality degradation will be regulated to achieve this level. A standard serves as a proxy for a damage function and, due to cost, is usually established without the estimation procedures discussed above. Figure 1 depicts the standard in terms of a damage function. Withholding a quantity greater than OQ_1 is of zero benefit to society and withholding a quantity less than OQ_1 is of infinite value to society. This means that a change in the cost functions of the firms involved will not change the equilibrium level of wastes withheld by the firms. The level of water quality (represented by withholding quantity OQ_1 of wastes) must be met at all costs.

Baumol [1972] has demonstrated that Pigouvian taxes or subsidies (tax or subsidy based on the amount of a firm's externality) are required for optimal allocation of resources, and that compensation to, or taxation of, those affected by the externality should not occur. However, the tax-subsidy approach has not been utilized due to the economist's inability to determine marginal social costs. 4/ Baumol and Oates [1971] have suggested an environmental

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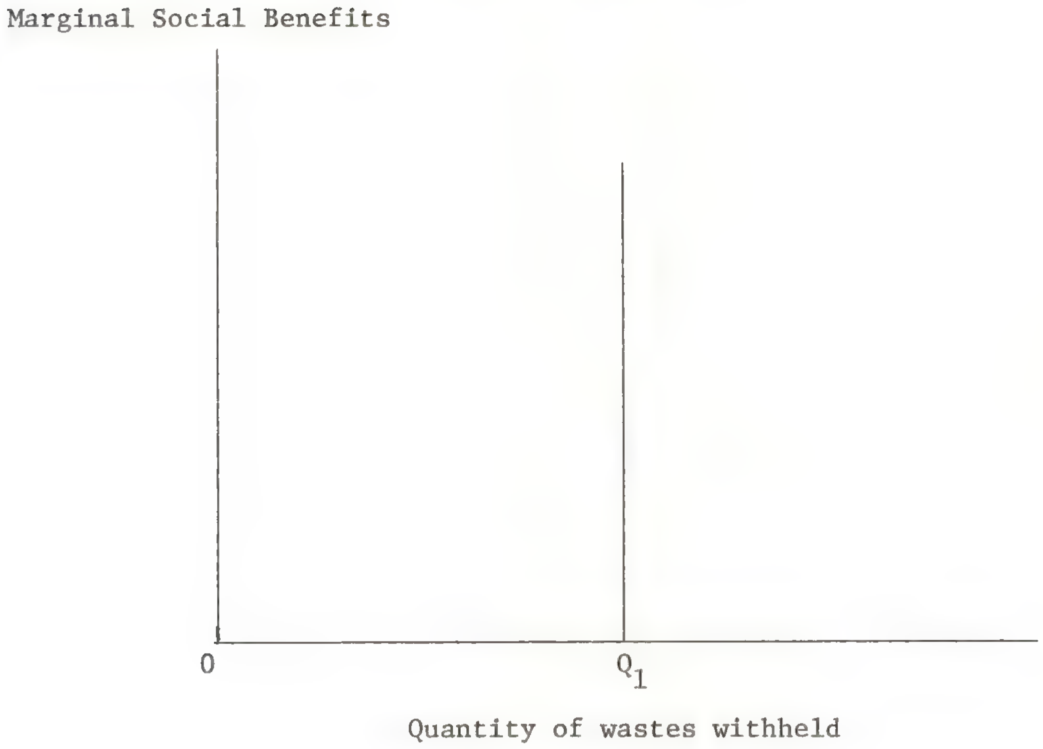
4/ See Kneese and Bower [1968] on the difficulties of establishing a tax subsidy system.

FIGURE 1. The Damage Function Implied by a Quality Standard



pricing and standards approach to the control of externalities. Such an approach involves establishment of a socially acceptable standard of environmental quality, and subsequent imposition of a system of charges on effluent emmissions to achieve that standard. This approach will not necessarily yield a Pareto-efficient allocation of resources; but, for any given vector of final outputs, the correct set of effluent charges can achieve the standard at the least possible cost.

The polluter (individual or firm) would react to the effluent charge (tax rate) by reducing the amount of effluent released which would in turn result in a higher quality environment. The firm would equate the effluent charge with the marginal cost of all effluent treatment alternatives, as the effluent charge represents the marginal cost of using the environment for waste disposal. The target level of environmental quality would eventually be achieved by adjustments in the effluent charge. One of the results of increasing the charge may be a reduction of the firm's optimal production level.

Baumol and Oates suggest that the level of effluent charges be determined by iterative adjustments until the desired standard is achieved. One disadvantage of this procedure is the probable occurrence of suboptimal investment decisions. Another drawback is that an environmental quality policy based on effluent charges might not be adopted without a projection of the level of effluent charges required over time to achieve the standard. Additional information, such as an evaluation of the initial reactions of those directly affected and an assessment of the subsequent economic and environmental consequences, is useful in comparing an effluent charge policy with alternative policies.

The method used to achieve a standard is important because the amount of waste reduction from each firm to achieve the standard at the lowest possible cost is unique to that firm. The use of an effluent charge, when properly specified, will achieve a water quality standard with greater efficiency and less administrative problems than other systems. The foremost problem of the effluent charge is to estimate correctly the level of charge that will yield a quality of water which meets the prespecified standard. The charge could be determined by experimentation or by estimating the marginal costs of each plant emitting wastes. 5/

Degradable wastes would change the conditions only if the point of discharge was located at a distance upstream where the standard was in effect. The effluent charge should be lower for the distant upstream firm than the charge to a firm discharging in the area directly effected by the standard. A firm located outside the area should be charged only the amount of decrease in water quality due to the release of its wastes. Since degradable wastes will cause less reduction in water quality, the difference must be reflected in the charge to the distant firm or an excessive waste treatment will be encouraged.

Multiperiod Linear Programming Model of the Westlands Water District

The hypothesis that an effluent charge system would achieve a minimum quality standard at the least cost when compared with alternative systems was tested empirically in the Westlands Water District. The model chosen for this analysis was a linear programming model that accounts for discrete time

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5/ See Kneese and Bower, 1968, p. 132.

periods with respect to both inputs and outputs. Models with such capabilities are usually referred to as multiperiod linear programming models. In this model, the amount of inputs available for the production of outputs in each time period is specified by a function of activities in past time periods. Each production alternative must be specified in each time period and the model must also include activities which transfer resources between time periods.

The multiperiod LP model has been used in a number of instances to analyze firm investments and temporal resource allocation problems.6/ This type of model has also been utilized to analyze the Brazilian steel industry, to develop a multiple-use management plan for a forested watershed and to determine an optimum time path of development for new irrigation districts.7/

The general multiperiod linear programming model is given as follows: the objective function is

$$\text{Max } f(X) = \sum_{k=0}^{t} \frac{C^k}{(1+r)^k} X^k \tag{1}$$

where C^k is an n dimension row vector of net revenues for the k^{th} time period; X^k is an n dimension column vector representing levels of crop production and resource use for the k^{th} time period; r is the rate of discount; $1/(1+r)^k$ represents the present net worth of $1.00 for the k^{th} time period. The constraints are

$$A^{11}X^1 \qquad \leq B^1 \tag{2}$$

$$A^{21}X^1 + A^{22}X^2 \qquad \leq B^2 \tag{3}$$

$$\begin{matrix} \vdots & & \vdots \end{matrix}$$

6/ See Loftsgard and Heady [1959], Smith and Heady [1960], and Martin and Plaxico

7/ See Kendrick [1967], House [1970], and Isyar [1970].

$$A^{k1}X^1 + A^{k2}X^2 + \ldots + A^{kk}X^k \leq B^k \qquad (4)$$

$$\vdots \qquad\qquad \vdots$$

$$A^{t1}X^1 + A^{t2}X^2 + \ldots + A^{tk}X^k + \ldots + A^{tt}X^t \leq B^t \qquad (5))$$

and

$$\sum_{k=0}^{t} X^k \geq 0 \qquad (6)$$

where A^{kk} is a m x n matrix of resource use coefficients for the k^{th} time period and B^k is a m dimension column vector of resources available in the k^{th} time period.

The specific linear programming model used in this study is as follows:

The objective function is to maximize the present value of Z:

$$\text{Max } Z = \sum_{t}^{\infty} PV^t \left(\sum_{i}^{4} \sum_{f}^{3} \sum_{j}^{19} C_{ifj}X_{ifj} - QW_p - PW_g - RN - Y - UNO_3 - VW_d\right)_t$$

where PV^t = the discount factor for year t.

$C_{ifj}X_{ifj}$ = the dollar returns to land and management from one acre of crop j grown on soil type i with f amount of nitrogen fertilizer times the respective activity level in acres in year t

QW_p = the cost of one acre-foot of project water times the respective activity level in acre-feet in year t

PW_g = the cost of one acre-foot of ground water times the respective activity level in acre-feet in year t

RN = the cost of one pound of N fertilizer times the respective activity level in pounds in year t

Y = the annual fixed costs of maintaining an NO_3-N treatment plant assumed constant over year t 8/

UNO_3 = the variable cost of removing one pound of NO_3-N from drainage water times the respective activity level in year t

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8/ The size of plant staged by time period and it is a function of the amount of projected acres requiring subsurface drainage.

VW_d = the variable cost of treating one acre-foot of drainage water (regardless of NO_3-N content) times the respective activity level in year t.

Subject to:

$$\sum_f \sum_j X_{ifj} \leq L_i \text{ for } i = 1, \ldots, 7$$

where L_i = total cropland acreage of land type i in year t.

$$\sum_i \sum_f \sum_j b_{ifj} X_{ifj} \leq \bar{W}_p + \bar{W}_g$$

where b_{ifj} = the water use per acre of crop j on land type i with N fertilizer level f.

$\bar{W}_p$ = the total acre-feet of project water available in year t.

$\bar{W}_g$ = the total acre-feet of groundwater available for use while maintaining a safe level of groundwater overdraft in year t.

$$\sum_i \sum_f X_{ifj} \leq M_j \quad j = 1, \ldots, 18$$

where M_j = marketing restraint on crop j in year t.

$$\sum_i \sum_f \sum_j n_{ifj} X_{ifj} \leq N$$

where n_{ifj} = the pounds of N used by one acre of crop with N fertilizer level f on land type i.

N = the amount of N fertilizer purchased by growers in the Westlands Water District.

$$\sum_i \sum_f \sum_j e_{ifj} X_{ifj} \leq NO_3$$

where e_{ifj} = the pounds of NO_3 in the drainage water from one acre of crop j grown on land type i with N fertilizer level f.

$$\sum_i \sum_f \sum_j w_{ifj} X_{ifj} \leq W_d$$

where w_{ifj} = the acre-feet of drainage water produced by crop j grown on land type i with N fertilizer level f.

The model is subject to the assumptions listed below.

1. The activities are linear and additive, i.e., the total output produced by all activities must equal the sum of outputs over individual activities. The same assumption is made with regard to the use of inputs. This assumption excludes any interaction between activities.
2. The levels of production and input use must be infinitely divisible into any fractional unit.
3. The model is deterministic, i.e., uncertainty is ignored.
4. Input prices remain at 1972 levels.
5. Agricultural producers are profit maximizers.
6. Profits are maximized for the Westlands Water District and not for each individual production unit.

Objective function.--The objective of the linear programming model is to derive a cropping pattern that maximizes over an infinite time horizon the present value of all future returns to land and management. The following several paragraphs describe the derivation of objective function values for cropping activities, reclamation activities, resource purchasing activities and drainage water treatment activities.

All major cropping alternatives available to producers in the Westlands Water District were included in the model. These included both annual and perennial crops. Each crop is included in the model as a set of alternative production activities, involving a particular combination of soil type and level of nitrogen fertilizer use. This configuration allows sufficient flexibility to analyze changes in production patterns and resource use that might be caused by changes in resource prices and/or the inclusion of a system of effluent charges. The basic LP model used in this analysis was originally developed by Yuksel Isyar to determine an optimum time path of development of the new irrigation districts on the west side of the San Joaquin Valley where Westlands Water District is located [Isyar, et. al. 1971]. A separate multiperiod LP model was developed by Isyar for each of the 13 districts including Westlands. Water use coefficients for the crop budgets in this model were taken from Isyar's Westlands Water District model.

Isyar's analysis employed three models in each district, each with a unique set of assumptions. The first model assumed that the district's future cropping plans would be implemented with no significant impact on prices. This model was specified since most irrigation feasibility studies are conducted under this type of assumption. An alternative model assumed that projected aggregate production in the State would have a significant effect on prices. This assumption was based on results of a study performed by Dean and King [1970]. Table 1 shows the projected acreage that would produce crops in "excess" of levels required to maintain constant market prices as determined by Dean and King. Table 2 shows the change in specialty crop price projections which would result from the "excess" acreage, based on estimates of price elasticities of demand. The percentage change in price is determined by dividing the percentage excess supply by the price elasticity of demand.

Table 3 lists the crops Isyar selected for analysis along with their respective projected prices assuming the excess supply has no effect on price and their corresponding depressed price assuming the excess supply will affect prices. The projected prices were determined by Isyar using average county

TABLE 1. Comparison of Projected Acreages of Specialty Crops with Acreages "Required" at Constant Prices

Region	1980			1990	2000
	Tree fruits, nuts, & grapes	Vegetables	Total	Tree fruits, nuts, grapes, & vegetables	Tree fruits nuts, grapes, & vegetables
	acres				
North Coast	15,000	--	15,000	17,000	19,000
Central Coast	145,000	225,000	370,000	320,000	270,000
South Coast	120,000	100,000	220,000	170,000	120,000
Sacramento Valley	310,000	70,000	380,000	460,000	540,000
San Joaquin Delta	310,000	160,000	470,000	455,000	440,000
San Joaquin Valley					
(non-westside)	880,000	170,000	1,050,000	1,255,000	1,460,000
(westside)	65,000	108,000	173,000	286,000	286,000
Desert	30,000	70,000	90,000	70,000	50,000
Intermediate elevation valleys	24,000	--	24,000	16,000	8,000
State acreage projected	1,889,000	903,000	2,792,000	3,059,000	3,193,000
State acreage "required"	1,813,000	833,000	2,646,000	2,796,000	2,947,000
State "excess acres"	76,000	70,000	146,000	253,000	246,000
Percent "excess acres"			5.5	9.0	7.7
Percent reduction from projection to maintain constant price			5.2	8.3	8.3

Source: Dean, G.W., and G.A. King, Projection of California Agriculture to 1980 and 2000: Potential Impact of San Joaquin Valley West Side Development, Giannini Foundation Research Report No. 312, Sept. 1970, p. 88; and Isyar, Yuksel, C.V. Moore, and G.W. Dean, Financial Analysis of Potential Agriculture Development on the San Joaquin Valley Westside, Giannini Foundation Research Report No. 316, July 1971, p. 23.

TABLE 2. Estimated Percentage Changes in Prices and Gross Returns for Selected Commodities [a]

Crop category	Estimated price elasticity of demand	Percent excess supply	Percent change in price	% change in gross return to industry
			percent	
Fruits, nuts, & grapes				
Deciduous fruits	-0.65	4.6	-7.1	-2.8
Tree nuts	-1.31	6.6	-5.0	1.3
Grapes	-0.23	4.0	-17.4	-14.1
Oranges	-0.66	2.3	-7.1[b]	-4.9[b]
Vegetables				
Cantaloupes	-0.50	4.9	-9.8	-5.4
Other vegetables	-0.35	2.3	-6.6	-4.5
Potatoes, early spring	-0.31	13.3	-42.9	-35.3
Other vegetables & potatoes	--	--	-13.2[c]	-9.38[c]

a/ Excess supply based on expert judgment considering recent trends.

b/ Dean and King assumed price reductions based on fresh market sales only, whereas in this study, larger portions are assumed to be allocated to the processing outlet.

c/ Weighted averages of other vegetables and potatoes.

Source: Dean and King, Projections of California Agriculture to 1980 and 2000 Potential Impact of San Joaquin Valley West Side Development, Giannini Foundation Research Report No. 312, September 1970, p. 109; and Isyar, Yuksel, C.V. Moore, and G.W. Dean, Financial Analysis of Potential Agricultural Development on the San Joaquin Valley Westside, Giannini Foundation Research Report No. 316, July 1971, p. 25.

TABLE 3. Field Crops, Vegetables, Fruits, Nuts, and Vines: Prices Selected for Analysis

Crop	Unit	Average price, 1962-68		Fresno County prices	
		State	Fresno	Projection I	Projection II [a]
		dollars			
Field Crops					
Sugar beets	ton	14.40	12.69	13.00	13.00
Beans	ton	217.00	188.57	200.00	200.00
Alfalfa seed	lb.	0.39	0.40	0.42	0.42
Cotton [a]	lb.	0.31	0.32	0.30[b]	0.30[b]
Field corn	ton	51.00	53.80	53.00	53.00
Barley	ton	40.00	47.66	47.00	47.00
Wheat	ton	40.00	51.00	50.00	50.00
Grain sorghum	ton	44.00	44.77	45.00	45.00
Vegetables					
Processing tomatoes	ton	35.50	32.00	26.00	24.28
Cantaloupes	ton	113.40	115.00	115.00	103.73
Nuts					
Almonds (in shell)	ton	641.00	596.67	600.00	570.00
Fruits					
Oranges, navel	cwt.	5.5.	6.30	5.00	4.65
Olives	ton	259.00	270.00	250.00	250.00
Nectarines	ton	120.00	220.00	200.00	185.80
Peaches, clingstone	ton	83.00	69.00	80.00	74.32
Vines					
Grape, wine	ton	61.00	57.79	75.00	61.95

[a] Projection II assumes increased supplies.

[b] Starting in 1972 at $0.30 per pound, price will decrease one cent each year and stabilize at $0.26.

Source: Isyar, Yuksel, The Potential Agricultural Development of the West Side of the San Joaquin Valley, California. Unpublished Ph.D. dissertation, Department of Agricultural Economics, University of California, Davis, June 1969, p. 102.

prices for 1962 and 1968.

The second model assumed the same gross acreage of specialty crops for the Westside, but allocated acreage to each district on the basis of its proportion of high quality soils. Variations in results were determined in the second model by first assuming constant prices and then depressed prices. The third model imposes the assumption that acreage of specialty crops is reduced sufficiently to maintain constant prices.

For the purposes of this analysis, the first model with the alternative assumption of depressed prices, (Table 3) was judged to be the most realistic and was used in deriving the crop budgets. Since these prices were projected, agriculture has had some significant price adjustments from the energy crises and increases in export demand. However, the present index of production cost (1967=100) is about 200 and the index of farm prices received are: vegetables 164, fruit 126, cotton 281, feed grains 199, and food grains 157. With the exception of cotton, the price projections assuming increased supplies and constant costs seems to reflect the relative profitability of the crops considered in this analysis.

Estimates of crop yields for the Westlands Water District were made by Isyar after consultation with crop experts (Appendix A). The soil classes, based on productivity and climatic conditions, were considered to be the most important variables in projecting yields.[9/] Table A-1 contains the crop yield estimates for the Westlands Water District by crop, soil class and level of nitrogen fertilizer application. Nitrogen was the only plant nutrient that was varied in the production process for two reasons. First, nitrogen is the

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[9/] Criteria for soil productivity are discussed in a later section.

only plant nutrient usually lacking in the soils of the west side of the San Joaquin Valley. Second, nitrogen will be a specific target of the waste water quality standard, which suggests an analytical model with agricultural production alternatives with respect to nitrogen use. Estimates of crop yield variation related to rates of nitrogen fertilizer application were derived from information in Ibach and Adams [1968], numerous state experiment station publications and the basic yield estimates from Isyar's study. Perennial crop yield responses to variations in nitrogen fertilizer were either nonexistent or the studies were only concerned with very small variations in nutrient levels. Table A-2 contains yield estimates by year for the perennial crops used in the analysis. These were derived from California Extension Service budgets adjusted for differences in climatic conditions and the advanced technology that will be employed by Westside producers.

Production costs were derived from California Extension Service budgets adjusted for price changes, production practices and yield differentials to 1970. Production costs include pre-harvest costs, harvest costs, depreciation and interest costs and drainage costs (if applicable). Water and nitrogen fertilizer costs, interest on land and all charges for management are excluded.

While water and nitrogen fertilizer costs are excluded from the budgets used to determine objective function values, they are included in the resource supplying activities of the model. By separating various resource requirements from the cropping activity budget, their alternative sources can be analyzed and the effect on production from changes in resource prices can be investigated with a minimum of analytical difficulty. For example, possible sources of water supplies include ground water, project water and water purchased from other districts. Each source is assumed to have limited supplies and different costs.

Since the subject of the analysis is subsurface drainage wastewater, separate cropping activities were included for soil types that will require drainage. The temporal nature of the drainage problems will be discussed later as a part of the soil constraints. With respect to production costs, an additional charge must be made for the construction and operation of a drainage system.

The monetary charge for nitrogen fertilizer was also removed from the crop budgets for those crops grown on drained soils. This procedure allows price variations of nitrogen fertilizer to approximate an effluent charge on the use of nitrogen. Measuring the effect of nitrogen use on the amount of nitrate nitrogen will be discussed in a later section.

The following assumptions were made with respect to the crop budgets [Isyar, 1971].

1. The wage rate for labor is $2.00 per hour.
2. The variable plus fixed costs are $1.45 per hour for a 30 horsepower tractor and $3.00 per hour for a 60 horsepower tractor.
3. The depreciation and interest cost is $1.00 per hour for a 30 horsepower tractor and $2.00 for a 60 horsepower tractor.
4. The interest rate is 5 percent.
5. Vines and citrus crops require a permanent set sprinkler costing $67.00 per acre. Vegetable crops require a solid set costing $67.00 per acre; and almonds, olives, and deciduous crops require a pull-hose system costing $40.50 per acre.

6. Annual depreciation, interest costs, repair and maintenance for a drainage system is $9.00 per acre [Yeary and Sheesley, 1969]. Tables 4 and 5 summarize production costs for annual and perennial crops, respectively.

All objective function values must be properly discounted to present values so that comparisons can be made when solving the multiperiod LP model. The following assumptions were made with respect to the discounting procedure.

1. Present values of the objective function are estimated over an infinite planning horizon.
2. Perennial crops are automatically replaced after a predetermined life.
3. The discount rate of 5 percent is used in all discounting calculations to make the results comparable to those of the U.S. Bureau of Reclamation's feasibility studies on the drainage and treatment plant in which the same discount rate was used.
4. Eight time periods are segmented: 1972-74, 1975-77, 1978-80, 1981-85, 1986-90, 1991-2000, 2001-2010, and 2011+.

The following procedures were used to determine the present value of returns from annual crops in each time period.

$$\text{1972-74} \quad PV_1 = R + \sum_{n=1}^{2} \frac{R}{(1.05)^n} \tag{7}$$

$$\text{1975-77} \quad PV_2 = \sum_{n=3}^{5} \frac{R}{(1.05)^n} \tag{8}$$

$$\text{1978-80} \quad PV_3 = \sum_{n=6}^{8} \frac{R}{(1.05)^n} \tag{9}$$

$$\text{1981-85} \quad PV_4 = \sum_{n=9}^{13} \frac{R}{(1.05)^n} \tag{10}$$

TABLE 4. Costs of Production of Annual Crops for the Westlands Water District (Excluding Charge for Water, Management, and Interest on Land) Assuming a 5 Percent Interest Rate

Crop	Unit	Yield/acre	Pre-harvest costs	Harvest costs a/	Depreciation and interest	Total costs
			dollars/acre			
Sugar beets	ton	26.5	102.23	66.25	22.71	191.19
Alfalfa seed	lb.	600	113.08	22.62	18.74	154.44
Cotton	lb.	1375	121.98	118.44	27.41	267.83
Dry beans	ton	1.547	53.60	57.26	22.76	133.62
Wheat & Dry beans						
Wheat	ton	2.0	90.73	70.00	22.76	183.49
Dry beans	ton	1.55				
Wheat & Milo						
Wheat	ton	2.0	97.55	30.00	22.16	149.71
Milo	ton	2.5				
Barley	ton	2.05	46.13	14.35	19.51	79.99
Tomatoes	ton	26.0	149.06	261.40	55.92	466.48
Cantaloupe, spring	ton	12.0	229.29	600.00	55.42	884.71
Cantaloupe, fall	ton	10.8	229.29	540.00	55.42	824.71
Cantaloupe, spring & fall	ton	22.8	458.58	1,140.00	55.42	1,654.00
Potatoes, spring	cwt.	250.0	217.41	281.00	53.92	540.33
Potatoes, fall	cwt.	225.0	217.41	253.00	53.92	524.33
Sweet corn, spring	cwt.	120.0	208.32	192.00	82.46	482.78
Sweet corn, fall	cwt.	90	208.32	144.00	82.46	434.78

Source: Cooperative Extension Service, University of California, Davis, "Sample Production Costs for Fresno County." 1967-1970.

TABLE 5. Costs of Production of Perennial Crops for the Westlands Water District (Excluding Charge for Water, Management, and Interest on Land) Assuming a 5 Percent Interest Rate

Crop	Year	Preharvest costs	Harvest costs	Depreciation & interest	Total costs
		dollars/acre			
Oranges	1	741.13	0.00	157.17	878.29
	2	115.56	0.00	107.17	222.72
	3	91.47	0.00	105.17	196.63
	4	105.66	13.75	107.17	225.57
	5	174.68	82.50	107.17	364.35
	6	198.88	151.25	107.17	457.30
	7	220.88	198.00	107.17	526.05
	8	244.26	253.00	107.17	626.42
	9	295.35	264.00	107.17	672.02
	10	295.35	264.00	107.17	666.52
	11	295.35	269.50	107.17	672.02
	12	295.35	375.00	107.17	677.52
Olives	1	123.16	0.00	39.50	162.66
	2	36.61	0.00	34.50	71.11
	3	37.82	0.00	34.50	72.32
	4	48.73	48.15	35.00	131.88
	5	55.61	92.85	34.00	183.46
	6	69.39	182.25	35.50	287.14
	7	124.14	271.65	38.00	433.79
	8	161.92	326.29	38.00	526.21
	9	200.97	371.99	38.00	610.96
	10	200.97	407.75	38.00	646.72
	11	200.97	434.57	38.00	673.54
	12	200.97	452.45	38.00	691.42
Peaches freestone	1	208.95	0.00	43.83	252.78
	2	75.96	0.00	43.83	119.79
	3	102.36	0.00	44.83	147.19
	4	155.16	0.00	44.83	199.99
	5	195.58	33.45	44.83	273.86
	6	235.18	85.45	44.83	365.46
	7	319.88	163.45	44.83	528.16
	8	356.46	202.45	44.83	603.74
	9	390.56	228.45	44.83	663.84
	10	420.45	241.45	46.33	708.24
Peaches clingstone	1	274.73	0.00	86.00	360.73
	2	83.16	0.00	76.00	159.16
	3	152.35	0.00	77.00	229.35
	4	341.22	71.36	82.00	494.58
	5	364.60	158.78	81.00	604.37
	6	393.75	231.92	80.00	705.67
	7	420.81	267.60	79.00	767.41
	8	452.49	303.28	78.00	833.77
	9	485.59	321.12	78.00	884.61

--Continued on next page.

Table 5(continued)

Crop	Year	Preharvest costs	Harvest costs	Depreciation & interest	Total costs
		dollars/acre			
Nectarines	1	195.97	0.00	70.08	266.05
	2	92.57	0.00	62.08	154.65
	3	117.87	0.00	62.08	179.95
	4	138.77	0.00	63.08	201.85
	5	174.14	33.45	64.08	271.67
	6	220.88	85.45	65.08	371.41
	7	822.98	163.45	66.08	512.51
	8	356.35	202.45	67.08	625.88
	9	427.63	215.45	71.08	714.16
Plums	1	172.87	0.00	70.08	242.95
	2	71.67	0.00	62.08	133.75
	3	107.97	0.00	62.08	170.05
	4	152.46	0.00	63.08	215.54
	5	215.38	19.80	64.08	299.26
	6	275.88	66.00	64.08	405.96
	7	335.78	120.00	65.08	520.86
	8	395.70	150.00	65.58	611.29
	9	395.70	171.00	65.58	632.29
	10	395.70	180.00	65.58	641.29
Almonds	1	243.89	0.00	104.75	348.64
	2	82.97	0.00	94.75	177.72
	3	105.22	0.00	95.25	200.47
	4	130.77	54.45	108.75	293.97
	5	194.13	64.05	111.75	369.93
	6	198.53	87.30	112.75	398.58
	7	201.83	99.90	112.75	414.48
	8	207.60	110.10	112.75	430.45
	9	213.10	118.70	112.75	444.55
	10	219.70	121.70	112.75	454.15
	11	225.20	128.30	112.75	466.25
	12	231.58	134.30	112.75	478.63
Grapes, wine	1	149.22	0.00	63.17	212.39
	2	317.79	0.00	55.17	372.96
	3	82.75	0.00	56.67	184.42
	4	94.08	90.00	56.67	240.75
	5	100.65	120.00	57.17	277.82
	6	108.44	135.00	56.67	301.10

Source: Cooperative Extension Service, University of California, Davis, "Sample Production Costs for Fresno County," 1967-1970.

$$\text{1986-90} \quad PV_5 = \sum_{n=14}^{18} \frac{R}{(1.05)^n} \tag{11}$$

$$\text{1991-2000} \quad PV_6 = \sum_{n=19}^{28} \frac{R}{(1.05)^n} \tag{12}$$

$$\text{2001-2010} \quad PV_7 = \sum_{n=29}^{38} \frac{R}{(1.05)^n} \tag{13}$$

$$\text{2011+} \quad PV_8 = \frac{R}{.05} - \left(\sum_{n=1}^{7} PV_n\right) \tag{14}$$

where PV represents present value and R annual returns.

Present values for perennial crops were determined by the following procedure. First, the present value of future returns over the life of each crop was calculated by the following formula:

$$PV = R_o + \sum_{n=1}^{m} \frac{R_n}{(1.05)^n} \tag{15}$$

where m is the expected life of the crop. Second, the annuity value was determined for the life of the crop by the following equation:

$$A = \frac{.05}{1-(1+.05)^{-m}} [PV] \tag{16}$$

where A is the annuity value. Third, the present value to infinity of the annuity was calculated using the conventional formula:

$$PV_A = \frac{A}{.05} \tag{17}$$

The present value of any perennial planted in a given time period is:

$$\text{1972-74} \quad \frac{PV_A}{(1.05)}$$

$$\text{1975-77} \quad \frac{PV_A}{(1.05)^4}$$

$$\text{1978-80} \quad \frac{PV_A}{(1.05)^7}$$

1981-85 $\frac{PV_A}{(1.05)^{11}}$

1986-90 $\frac{PV_A}{(1.05)^{16}}$

1991-2000 $\frac{PV_A}{(1.05)^{23}}$

2011+ $\frac{PV_A}{(1.05)^{39}}$

The Reclamation Activities.--The irrigable soils of the western San Joaquin Valley were classified into four classes based on productivity, slope, permeability and climate [Isyar, 1970, pp. 43-44]. Class A soils are the most productive, do not have any serious defects and are capable of growing all of the crops selected for this analysis. The productivity of soil B is slightly less than soil A and it contains somewhat more salts and boron. All of the crops selected for this analysis can be grown on these soils except dry beans and tree crops which are sensitive to salts and boron. Soil B can be brought up to soil A standards by reclamation.

Class C soils are lower in productivity than class B soils and exhibit problems of drainage, boron, and salts. Some class C soils can attain the properties of class B soils by reclamation. Class D soils are less productive than the other soils and produce only those crops which have high tolerance to boron and salts. Leaching class D soils will eventually up-grade them to class C standard, but the time and expense involved is excessive.

To up-grade soils to the next higher class, irrigation water must be applied to leach excessive salts and boron from the soil profile and then removed by subsurface drains. The model allowed class C soils to be up-graded to class B standards by the application of 3 acre-feet of water over a two year period. Crops are not grown on soils under reclamation.

Reclamation was not included for class B soils as there was enough acreage of class A soils to accommodate the market share acreage requirements of tree crops and vegetables. Additional class A soils would produce only lower-valued crops, and the revenue generated from increased yields of these crops is smaller than the cost of reclamation.

Water Purchasing Activities.--The water requirements of the district can be met by either project water or ground water supplies. The available water supply and the schedule of water costs over time are indicated in Table 6. Since the price of ground water is considerably more than the price of project water, ground water supplies will probably serve as a residual source.

Nitrogen Fertilizer Purchase Activity.--The cost of nitrogen fertilizer was excluded from the budgets for crops that were to be drained, and those nitrogen requirements were satisfied by the nitrogen purchase activity. This allowed the price of nitrogen to be varied from current levels to determine the effect of different nitrogen prices on production. The base price used for applied nitrogen was 10 cents per pound.

Wastewater Treatment Activities.--The costs of removing NO_3-N from subsurface drainage water by several methods have been approximated by the Agricultural Wastewater Study Group in research conducted at Firebaugh, California [California Department of Water Resources, 1971]. A bacterial denitrification process in a filter configuration was the least expensive method evaluated and the cost function was used in the LP model. The cost function (C) in 1970 dollars is:

$$C = \$284{,}144 + \$21.52W + \$0.12\,[NO_3\text{-}N]\,W \qquad (18)$$

TABLE 6. Projected Water Availability and Cost in the Westlands Water District

	1972-74	1975-77	1978-80	1981-85	1986-1990	1991-2000	2001-2010	2010+
Ground water available a/	609	547	508	485	480	479	479	479
Cost of pumping ground water b/	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50
Project water available a/	525	800	1,060	1,091	1,091	1,091	1,090	1,090
Project water cost b/	9.00	11.67	13.00	13.00	13.00	13.00	13.00	13.00

a/ 1,000 acre-feet.

b/ Per acre-foot.

Source: Bureau of Reclamation and Yuksel Isyar, *The Potential Agricultural Development of the West Side of the San Joaquin Valley, California*. Unpublished Ph.D. dissertation, Department of Agricultural Economics, University of California, Davis, December 1970.

where W is the amount of drainage water expressed in acre-feet and NO_3-N is expressed in pounds (2.7164 lbs. NO_3-N/a.f. of water with 1 ppm NO_3-N).

This cost function is based on annual flows ranging from 5,000 acre-feet to 155,000 acre-feet. Capital expenditures for the various volume processes ranged from $10.3 million to $47.9 million. Interest is charged at the rate of 5 percent and the cost of nitrogen removal is for methanol which is required in direct proportion to the amount of nitrogen in the water.

Soil Constraints.--As discussed above, the soils were divided into four classes on the basis of many factors. The projected acreage of irrigable land and the amount of land that will require drainage is presented in Table 7. The availability of irrigable land over time was projected by personnel in the Westlands Water District [Isyar, 1970, pp. 114-118], based on estimated completion dates of water delivery systems. The projected acreage that will require drainage is based on the capacity of planned drainage collection facilities estimated by the Bureau of Reclamation [De Bruyn, 1971].

Water Constraints.--Delivery of project water during the peak period months of July and August is restricted to 36 percent of the total annual supply due to limited capacity of delivery systems and existing contractual arrangements [Isyar, 1970, pp. 118, 123]. The ground water safe yield limits pumping to about 60 percent of the total annual supply during July and August. The total and peak period water supplies are given in Table 8.

Market Constraints.--The District's actual cropping plans were used to limit the acreage of the various crops over time. This is to guarantee a normal cropping diversity throughout the district and to insure that the

TABLE 7. Total Irrigated and Acres of Irrigated Land that Will Require Drainage by Class and Time Period

Class	Soil	1972-74	1975-77	1978-80	1981-85	1986-90	1991-2000	2001-2010	2010+
		1,000 acres							
A	Irrigated land	170	181	190	193	193	193	193	193
	Require drainage	--	--	--	--	--	12	31	38
B	Irrigated land	189	203	214	218	218	218	218	218
	Require drainage	--	--	--	--	6	60	77	82
C	Irrigated land	65	74	74	75	75	75	75	75
	Require drainage	--	--	1717	44	75	75	75	75
D	Irrigated land	56	66	65	67	67	67	67	67
	Require drainage	--	--	16	39	67	67	67	67

Source: Bureau of Reclamation and Yuksel Isyar, ibid., p. 17.

TABLE 8. Projected Annual Total and Peak Period Water Supply

	1972-74	1975-77	1978-80	1981-85	1986-1990	1991-2000	2001-2010	2010+
	1,000 acre-feet							
Total water available	1,134	1,347	1,568	1,576	1,571	1,570	1,569	1,569
Peak period water available a/	554.4	616.2	686.4	683.76	680.76	618.16	679.8	679.8

Source: Personal interview with Mervin Dehaus, Bureau of Reclamation (USDI), Sacramento, CA, Sept. 1, 1971.

a/ Peak period refers to July and August.

TABLE 9. Projected Acreages of Crops in the Westlands Water District

Crop	1980	2000
	acres	
Sugar beets	14,340	37,940
Alfalfa seed	11,154	24,446
Dry beans	141	6,575
Cantaloupes	2.878	5,463
Tomatoes	2,682	8,512
Other vegetables	23,156	40,924
Oranges	18,774	26,976
Olives	18,774	26,976
Deciduous fruits	6,938	9,560
Tree nuts	33,079	50,223
Grapes	3,429	6,858
TOTAL	135,345	243,453

Source: Isyar, Yuksel, ibid, p. 135.

assumptions made earlier regarding product prices will not be violated.

Water Requirements.--Annual and peak period (July and August) irrigation water requirements for the crops used in this analysis are listed in Table 10. The requirements were developed from California Department of Water Resources data and information from the University of California Experiment Station.

NO_3-N in Drainage Water.--There is little agreement among experts on the extent of the nitrogen problem. Commoner [1968] has contended that at least 15 percent of the nitrogen fertilizer applied in the United States eventually is found in surface water, and another 15 percent is lost to the atmosphere. He has called for a 10-year moratorium on the use of nitrogen fertilizer in the United States, and is currently conducting research to test his contentions. Viets and Hageman [1971] concluded from a search of the literature that the nitrogen pollution problem has not reached a crisis. They suggest that since applications of nitrogen are important in maintaining an adequate supply of agricultural commodities, procedures other than a ban on nitrogen should be explored. They report there is little indication of a general increase in the nitrogen content of the nation's water supplies, but that surface and ground water in regions of intensive agriculture are high in nitrogen. Viets and Hageman suggest that research efforts be concentrated on identifying and reducing or eliminating, the natural sources of nitrogen within those regions.

Cultivation and related agricultural practices are the primary causes of nitrogen loss from the soil, but little evidence is available to indicate the amount of loss by source. Nitrogen is usually lost through crop removal, erosion, nitrate leaching, and denitrification. Despite continuing research on this topic, some of the basic nitrogen transformations are little understood

TABLE 10. Annual and Peak Period Water Requirements for Selected Crops

Crop	Water requirements	
	Annual	Peak[a/]
	acre-feet	
Sugar beets	2.58	0.75
Dry beans	3.00	1.00
Wheat/dry beans	3.50	1.00
Alfalfa seed	2.50	--
Cotton	3.17	1.67
Wheat/milo	4.00	1.17
Barley	1.25	--
Tomatoes	3.00	--
Spring vegetables	2.00	0.33
Fall vegetables	1.25	0.58
Spring/fall vegetables	3.25	0.91
Oranges:		
Year 1	1.00	0.33
Year 2	2.00	0.65
Year 3	2.50	0.82
Year 4	3.00	0.98
Year 5	3.60	1.14
Year 6+	4.13	1.38
Deciduous:		
Year 1	1.00	0.34
Year 2	2.00	0.68
Year 3	2.50	0.86
Year 4	3.00	1.03
Year 5	3.50	1.20
Year 6+	4.00	1.37
Grapes:		
Year 1	1.00	0.42
Year 2	2.00	0.83
Year 3	2.50	1.04
Year 4+	3.00	1.24
Almonds:		
Year 1	1.00	0.50
Year 2	2.00	1.00
Year 3	2.50	1.25
Year 4	3.00	1.50
Reclamation of soil C to B		

Source: Isyar, Yuksel, ibid., p. 143.

[a/] Peak period refers to July and August because of their complex nature. Nitrogen in the soil originates from many sources other than commercial fertilizers. Organic matter, symbiotic or non-symbiotic fixation of atmospheric nitrogen and assimilation of atmospheric nitrogen by micro-organisms, contribute relatively large amounts. Alternative sources of nitrogen, and the complexity of its movement in the soil, are among factors making it difficult to determine the causal relation between the application of nitrogen fertilizers and the nitrate-nitrogen content of surface and ground water.

Nitrogen is usually the limiting nutrient in crop production, and this need is satisfied primarily with applications of commerical fertilizers. Unlike most nutrients in the soil, nitrogen in nitrate form is water soluble, and is highly mobile in the soil strata. Some environmentalists have linked the occurrence of nitrogen in bodies of water close to agricultural areas with the increasing use of nitrogen fertilizers. Nitrogen in surface water has been shown to induce excessive growth of algae and other aquatic plants that require high amounts of oxygen when they die and decompose. Health problems have occurred when ground water of high nitrate-nitrogen content has been used for human and animal consumption.

A multiple regression model was developed to test the hypothesis that the amount of NO_3-N in subsurface drainage water is correlated with the amount of nitrogen fertilizer applications and the soil series being drained. A soil series is a group of soils having similar horizons and arrangement in the soil profile and are formed from a particular type of parent material. Individual series are given names from place names near the first recorded occurrence. The structural equation was of the form:

$$X = \alpha + \beta S_j + \gamma Y + U \qquad (19)$$

where X is the pounds of nitrate-nitrogen (NO_3-N) per acre-foot of drainage water; and S_j represents a set of soil series shift variables with the particular soil series in question having a value of one and the others then assuming a zero value; Y is the pounds of nitrogen (N) fertilizer applied per acre. The slope of the function was held constant over the various soil series but quantitative variations in the intercepts were allowed through the use of the soil series shift variables.

The model was applied to cross sectional data from 38 tile drains located in the San Joaquin Valley [California Department of Water Resources, 1971]. The characteristics of the tile drainage systems in the sample are presented in Table 11. The year 1967 was selected for analysis because corresponding N fertilizer application rates were available in this year only. The system employed to select a sample is explained in the California Department of Water Resources publication cited above.

The physiographic position of the soil series included in the sample are given in Table 12 to illustrate the similarities in the formation of the various soil series. The physiographic position provides information on how the various soil series were formed, the mineral content, the structure and the nature of the parent material.

The model was originally structured to accommodate 13 soil series shift variables (S_j's). Estimates of the parameters of 10 of the 13 variables were not significantly different from zero and the model was restructured utilizing the three significant variables: Panoche, Panhill, and Lost Hills.

The estimated coefficients and their standard errors for two equations are given in Table 13. The estimate of the intercept value of the first

TABLE 11. Characteristics of Sample Tile Systems in 1967

System number	Total acres	Soil series	Flow	NO_3-N	NO_3-N	Applied N	Water* ap-plied
			ac.ft./ac.	lb./ac.	mg./L.	lb./ac.	ac. ft./ac.
1	380	Sorrento	2.2	52	8.6	90	3.6
2	113	Sacramento	2.2	25	4.3	74	4.2
3	475	Sorrento	1.1	21	7.0	22	2.3
4	209	Rincon	.3	8	10.2	0	1.6
5	82	Ambrose	.8	15	6.7	0	3.5
6	420	Rincon	1.8	31	6.4	98	2.7
7	220	Sorrento	1.2	45	13.9	83	3.2
8	22	Ambrose	.2	4	7.9	125	2.0
9	750	Sorrento	.4	7	6.5	85	4.2
10	334	Sorrento	.8	23	9.6	92	4.5
11	292	Rincon	.7	18	9.2	122	3.1
12	50	Sorrento	.7	15	8.6	24	2.9
13	491	Oxalis	.8	27	11.1	134	3.8
14	110	Oxalis	.52	9	6.4	159	3.8
15	240	Panoche	.82	125	56.2	150	3.3
16	200	Panoche	.50	78	57.8	88	3.7
17	160	Panoche	1.0	173	64.0	150	3.3
18	200	Panoche	1.3	131	37.1	70	4.4
19	270	Panoche	.74	37	18.2	105	3.1
20	307	Panhill	.58	67	42.2	38	3.4
21	250	Oxalis	.51	8	5.6	0	3.2
22	672	Panoche	.18	9	19.1	106	2.9
23	17	Panoche	2.8	296	39.0	343	2.0
24	120	Panoche	3.01	309	37.9	82	4.0
25	145	Panhill	1.78	222	46.0	100	2.5
26	200	Panhill	2.03	243	44.3	78	3.1
27	138	Lost Hills	1.54	136	47.2	0	4.0
28	313	Oxalis	.66	12	6.6	79	3.7
29	230	Lethent	.58	44	27.7	136	5.5
30	140	Willows	.80	11	5.2	100	7.2
31	320	Panoche	.03	1	12.0	0	4.5
32	160	Lethent	1.03	30	10.7	160	4.0
33	80	Lost Hills	1.82	331	67.2	100	2.5
34	580	Tulare	.51	12	8.4	0	4.5
35	120	Hacienda	1.49	64	15.9	90	3.0
36	325	Tulare	.57	7	4.8	127	2.6
37	60	Tulare	.58	10	6.4	100	3.0
38	73	Foster	.61	21	12.8	125	2.2

*This information was not obtained from operators. This is the amount of water recommended for the cropping pattern that existed in 1967.

Source: California Department of Water Resources

TABLE 12. Physiographic Positions of Different Soil Series

Soil Series	Physiographic position
Panoche	Recent alluvial fan
Sorrento	
Panhill	
Foster	
Lost Hills	Older alluvial fan
Rincon	
Ambrose	
Oxalis	Basin rim
Willows	
Levis	
Lethent	
Tulare	Basin
Columbia	
Sacramento	
Hacienda	

Source: California Department of Water Resources, Nutrients From Tile Drainage Systems, Bio-Engineering Aspects on Agricultural Drainage, San Joaquin Valley, California, May 1971, p. 23

TABLE 13. Results of Regression of Pounds per acre of Nitrogen in Tile Drains on Applied Nitrogen and Soil Series. [a/]

Equation number	Constant term	Lost Hills	Panhill	Panoche	Applied N	R^2	Durbin-Watson
					lb./ac.		
1	-27.6	231.9 (35.9)	194.4 (26.2)	60.1 (20.5)	.583 (.131)	.760	1.88
2	--	218.7 (33.3)	188.2 (24.3)	49.3 (19.9)	.296 (.094)	.735	

[a/] Standard errors are shown directly under the coefficients.

equation relates to soil series other than Panoche, Panhill, and Lost Hills and it was negative. Since negative NO_3-N yields are impossible to achieve in reality, a second equation was estimated with a suppressed constant. The coefficient of multiple determination for equation 1 was .760 with all coefficients significant at the one percent level. The coefficients for the three shift variables are obtained by allowing the nitrogen application -- NO_3-N function to shift its location with the three soil series while keeping the slope of the function the same over the various soil series. The magnitude of these coefficients indicate the importance of the soil series in explaining the amount of NO_3-N in tile drains. Lost Hills soils have the most influence with a positive change in intercept value of 231.9 pounds of NO_3-N. Panhill soils have almost as much effect by shifting the function 194.4 pounds, while the Panoche series causes the function to shift by 60.1 pounds. The influence of N applications is relatively high with .583 pounds of NO_3-N resulting in the drainage water for every pound of N applied. The Durbin-Watson statistic indicates the absence of serial correlation.

Forcing the regression line through the origin lowered the coefficient of determination from .760 to .735 which is not an excessive reduction in explanatory power. However, the magnitude of the coefficient of the N application -- NO_3-N function -- is reduced by almost half. A flatter function would be expected because of forcing the positive sloped regression line through the origin from a previous negative intercept. In the second equation, the coefficients of the soil series shift variables are only slightly smaller. All of the coefficients of equation 2 are significant at the 1 percent level.

Equation 2 was selected over equation 1 to predict the effects of N applications on the amount of NO_3-N in tile drains. Logarithmic and other nonlinear functional forms were tested but the linear form proved superior in all tests of significance and prediction powers.

EMPIRICAL RESULTS

The Westlands Water District and the Bureau are responsible for the deliveries of irrigation water and the collection and disposal of drainage water. If the disposal costs cannot be shifted to the general taxpayer, one objective may well be to minimize the costs of achieving the standard by utilizing the effluent charge system or by recovering the nitrate removal costs by increasing the price of project irrigation water.

NO_3-N Charge and Treatment Alternatives

Charging the individual farmer on the basis of the NO_3-N concentration in the drainage water from his land would represent the internalization of the social costs or externalities to the responsible economic unit. Since there exists a collective treatment alternative, the District must estimate either the level of effluent charge that will reduce the NO_3-N concentrations to achieve the desired quality standard (NO_3-N charge alternative), or the level of effluent charge that will produce sufficient revenue to treat the drainage water (treatment alternative). The cost of achieving the standard by each alternative is not the same. The social cost of N pollution is based on concentration and mass emissions, and it increases with the amount of NO_3-N and decreases with the quantity of water. This contrasts with the nature of the treatment cost function which has a substantial amount of fixed costs, increases with the quantity of water, but increases only slightly with the amount of NO_3-N (Equation 18). The District must choose between the mutually exclusive alternatives (treatment or charge system) the policy that optimized capital investments in treatment and drainage facilities over time.

The 609,000 acre-feet of ground water presently available for pumping is expected to decrease to 479,000 acre-feet by 1995. Project water deliveries will increase from the present level of 525,000 acre-feet to 1,091,000 acre-feet by 1983. The cost of pumping ground water is expected to remain constant over time at $22.50 per acre-foot,[10/] whereas the price of project water will increase from the present $9.00 per acre-foot to $13.00 by 1979.

Two costs of achieving the specified quality standard of 2ppm under each of the two alternative policies are presented in Table 14. The cost is defined as the reduction in income plus the costs of treatment due to the standard. Since the objective function of the linear programming model is expressed as the present value of all future returns to Westlands producers, the costs were calculated as the difference between income derived from the optimal cropping pattern without the standard and income derived from the optimal cropping pattern with the standard. Therefore, the total costs to achieve the standard represent those costs associated with reducing farm output or changing agricultural practices, and/or those costs associated with amortizing the construction costs and maintaining and operating a treatment plant.[11/]

Total annual income for the District is $40,626,000 if no restrictions are placed on drainage water disposal. Achieving the standard reduced the total income to $40,101,000 utilizing the NO_3-N charge alternative and to $39,094,000 utilizing the treatment alternative. On a total district per acre

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[10/] Long run increased energy costs are assumed to be offset by improvements in pumping efficiency and rising water tables due to increasing use of project water.

[11/] Excludes transactions costs.

TABLE 14. Estimates of the Cost to Achieve a 2 ppm NO_3-N Standard on Subsurface Drainage Water in Westlands Water District and the Resulting Resource Use*

Average annual district values (552,512 acres)	Unit	Without standard	With standard: NO_3-N charge alternative	With standard: Treatment alternative
Total income	$1,000	40,626	40,101	39,094
Total income per acre	dollar	73.53	72.55	70.76
Total cost of standard	$1,000		525	1,532
Cost per acre	dollar		.95	2.77
Drained land [a/]	acre	83,412	59,931	79,782
Idle land as result of standard	acre		26,481	3,630
N applied per acre of drained land	pound	54.8	3.7	30.3
Drainage water per acre of drained land	acre-ft.	.67	.57	.56
Total drainage water	acre-ft.	55,886	32,451	45,017
NO_3-N concentration in drainage water	ppm	20.7	2.0	4.7[b/]
Production of:				
Field crops	acre	283,628	257,888	276,667
Fruits, nuts, and grapes	acre	82,335	82,335	82,116
Vegetables	acre	46,799	46,700	46,799

* Appendix A contains cropping patterns, incomes and resource use over time from which these data were derived.

a/ Drained land is defined as land under cultivation with a water table less than five feet below the surface and requiring subsurface tile drainage to be fully productive.

b/ NO_3-N concentration of drainage water prior to treatment.

c/ Crop acreage includes double crops. Detailed crop patterns by soil type, drainage conditions and quality alternative are presented in Appendix C.

basis, the reduction in income is \$0.95 and \$2.77 for the two alternatives, respectively.[12]

The hypothesis that the NO_3-N charge system would achieve the water quality standard at the lowest possible cost is substantiated. The total District cost of achieving the standard, using the NO_3-N charge alternative is \$525,000 annually of which \$450,954 is reduced annual income caused by production adjustments and \$74,046 are collected by the District.[13] The cost of the treatment alternative is \$1,532,000. Of this total, \$61,710,000 represents loss in annual farm incomes and \$1,469,909 represents treatment costs.[14] The total cost of the NO_3-N charge system is 34.3 percent of the treatment cost system.

Some of the production adjustments are in the form of reductions in the acreage of field crops and growing them on soils that contain low amounts of native nitrogen. The acreages of other classes of crops remain almost constant, with or without the standard involved. The acreage of field crops estimated under the NO_3-N charge is 25,740 acres less than optimal production without a standard and 6,961 acres less if the treatment alternative is used. Most of this reduction in acreage represents cotton which requires large amounts of water and nitrogen fertilizer inputs relative to some of the other field crops considered, such as alfalfa seed. The amount of idle land increased by 26,481 acres and 3,630 acres, respectively. The change in the crops grown on drained land reduces the nitrogen use from 54.8 pounds per acre of drained land when the standard is not in effect to 3.7 and 3013 pounds per acre of drained land respectively when the standard is achieved using the two alternatives. The changes in cropping pattern would probably not affect prices since these results apply only to Westlands Water District or to areas that would have a separate subsurface drainage collection systems. This has been proposed for the San Joaquin Valley but the project has not been financially feasible for individual districts.

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[12] The per acre decrease in income was determined using 552,512 acres as the denominator, which ignored the changes in the farm units whose income is directly affected. This aspect will be discussed later.

[13] The charge is \$0.42/1b. of NO_3-N.

[14] Loss in annual farm income occurred with the treatment alternative because it was less costly to adjust production to avoid some of the treatment costs.

Decreases in the amount of drainage water is chiefly the result of a reduction in drained land under production, rather than the amount of drainage water per acre. However, the decrease in NO_3-N concentration is due to less N fertilizer use and the placement of crops on those soils which minimize the leaching of natural nitrogen from the soil (see Appendix C). In the case of the NO_3-N charge, the 2ppm standard is achieved with an average annual charge of $0.42 per pound of NO_3-N. The average revenue collected by the District in achieving the standard is $74,046 annually. These results would indicate that if the District was going to charge individual farmers to achieve the standard according to the amount of drainage effluent each produced, the NO_3-N charge would probably not only be the lower cost alternative, but would also eliminate the irreversible investment in a treatment plant.15/

Monitoring costs are explicitly ignored because the California Department

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15/ The possibility of lower cost treatment alternatives designed to remove NO_3-N from drainage water containing 5-15 ppm should be explored. The upper limit on the annual cost for treatment would, of course, be the amount collected from the NO_3-N charge which is $74,046 and the NO_3-N charge of $0.42 per pound would reduce NO_3-N levels to 2 ppm.

of Water Resources currently monitors most tile drain effluents. Public Law 92-500 and the NPDES permit system will also require extensive waste water monitoring.

The amount of farmland removed from cultivation due to the imposition of the standard is 26,481 acres if the NO_3-N charge is used and 3,630 if the treatment cost function is used. Most of this land is located in the lower elevations or the east side of the Westland Water District. The displacement of farm families and the lost incomes raises serious equity questions that must be considered. Moore [1965], in an economies of size study in Western Fresno County, concluded that substantially all of the cost economies were achieved by farms of about 560 acres in size. If one assumed that this size of farm was representative of farms in the area, a land area equivalent to about 41 farms would be lost under the NO_3-N charge system, and 39 farms would be idled under the treatment cost system. Moore also estimated that each farm of this size would generate about $150,000 in annual gross income.16/ The difference in the number of farms lost using one system to achieve the standard versus the other system is probably not significant. However the reduction in farms and the loss of aggregate income as a result of the standard (incidence and impact) are social questions that should be considered as a cost of achieving a desired level of water quality. In addition to the loss of farm incomes, reductions in secondary incomes within the region and the welfare effects due to changes in commodity prices could also be considered in evaluating policies to achieve the standard. Certainly compensation to those adversely affected could

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16/ The average size land holding for the Westlands Water District is 227 acres. However, 76 owners held virtually all of the productive acreage and 18 farms owned 203,000 acres or 35 percent of the District, Fellmeth [1971, p. 37].

be considered by policy makers. Most of the area that would probably go out of production is located in the lower elevations or trough of the San Joaquin Valley.

Allocating NO_3-N Removal Costs to the Public Sector

The alternatives just discussed could be used if the cost of achieving the standard were imposed on the District landowners. Two other alternatives open to the District are to allocate the treatment costs to the general taxpayer via Congressional legislation or to recover the costs of treatment by increasing the cost of project water.17/ The first alternative insures that the standard will be achieved without imposing any incentives on farmers to change their practices to improve drainage quality. This policy is clearly in the best interests of the District and the farmers but socially suboptimal.

The average annual cost of the public sector18/ for NO_3-N removal can be determined from the average annual drainage water NO_3-N concentrations generated as a result of no standard (Table 16). Equation 23 establishes the cost of nitrate removal.

$$C = \$284,144 + \$21.52W + \$0.12\ N$$

where C is cost, W is drainage water in acre-feet, and N is NO_3-N in pounds. Without a standard, the District will generate 55,886 acre-feet of drainage water at an average NO_3-N concentration of 20.7. Therefore, the average annual costs of achieving the standard is:

$$C = \$284,144 + \$1,202,666 + \$377,092^{*} = \$1,863,902$$

*\$0.12 x 55,886 x 20.7 x 2.7164; where 2.7164 is the number of pounds of NO_3-N in one acre-foot of water with one ppm of NO_3-N.

17/ The latter policy of recovering costs has the highest probability of implementation.

18/ The cost of public acceptance of the amortization schedule on the treatment plant and its operation and maintenance.

This solution is more expensive than the two alternatives considered. However, the costs would be borne by the entire public sector rather than by producers.

Allocating NO_3-N Removal Costs to District Landowners by Increasing Project Water Costs

Adding the cost of NO_3-N removal to the cost of project water delivered to farmers is a probable policy. This alternative involves a small amount of additional institutional and administrative costs and provides an incentive for the prudent use of irrigation water by farmers.

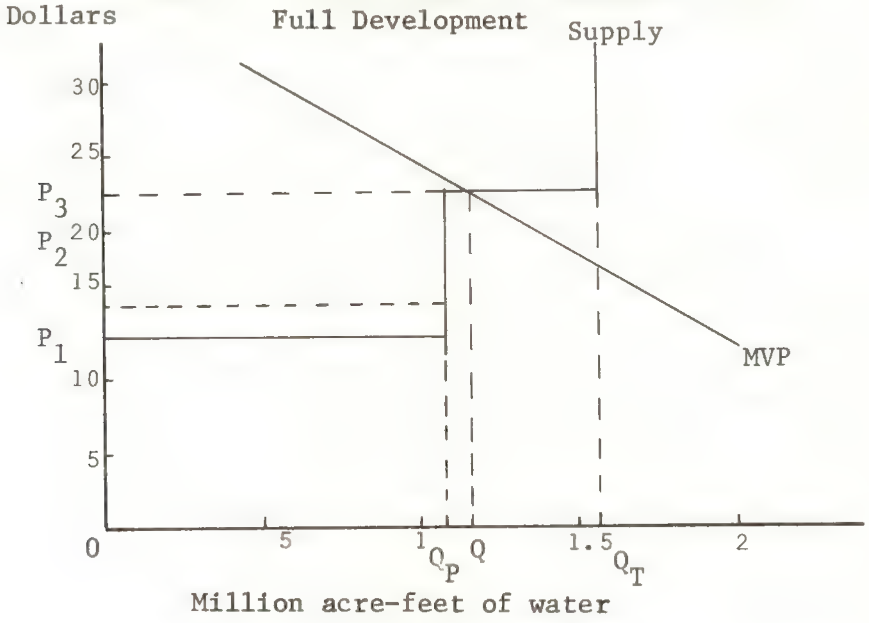
The average annual removal costs of $1,863,902 were divided by the 1,090,000 acre-feet of water delivered at full development. The per acre-foot cost of $1.71 was added to the project water cost of $13.00 and the cropping pattern and resource use was optimized.

The cropping pattern was precisely the same as the one derived without imposing a standard (Table 14). However, farm incomes were annually $1,863,902 lower. This compares to annual income losses of $525,000 for the NO_3-N charge alternative and $1,359,000 for the treatment alternative.

This can be explained by the following graph of water supply and demand functions. The supply function was derived using the supply of project water, 1.09 million AF (Q_p) and the supply of available ground water, 479,000 AF (Q_T-Q_p). The marginal value produce of water schedule shown was not estimated except for point Q, the actual amount of water used in the optimal cropping pattern.

The increase in project water costs from $13.00 ($P_1$) to $14.71 ($P_2$) does not affect the total use of water (Q) because P_2 is less than the MVP of water ($22.50). If the cost of project water and treatment exceeded $22.50, a decrease in the use of water and an alternative optimal cropping pattern would be expected. This policy effects a transfer of the removal costs to the District landowners on the basis of water use without causing a change in the production of agricultural commodities. Another result is a transfer back to society of a portion of the income from the landowners who use subsidized project water.

FIGURE 6. The Demand and Supply of Project and Ground Water in the Westlands Water District at Full Development



Land and Water Use

Table 15 presents projected land use for the District after full development. The amount of idle land is substantial with or without the imposition of a quality standard on drainage water. The total amount of land available at full development irrigation is about 553,000 acres. Without the standard, about 386,000 acres will be in production. None of the class C and D land will be in production due to the high water table and the lack of profitable crops adaptable to these low productivity soils. Crops that were profitable prior to a high water table will not cover the costs of installation and operation of a subsurface tile drainage system. Imposition of the quality standard reduces land use from 386,000 acres to 360,000 acres using the NO_3-N

TABLE 15. Estimates of Land and Water Use in the Westlands Water District, 1990-2011+

Average annual District values (552,512 acres)	Total available	Without standard	With standard	
			NO_3-N charge alternative	Treatment alternative
Land use (1,000 acres)[1]				
Class A	193	169	163	163
Class B	218	217	193	217
Class C	75	0	4	2
Class D	67	0	0	0
Total	553	386	360	382
Water use (1,000 ac. ft.)				
Project water	1,090	1,090	1,090	1,090
Ground water	479	94	18	77
Total	1,569	1,184	1,108	1,167

[1] Cropping Pattern by soil class and drainage condition is presented in Appendix C.

charge alternative and to 382,000 acres using the treatment alternative. The introduction of more profitable crops on class C and D soils or higher long-run commodity prices or a change in technology could change the economic feasibility of drainage.

The use of irrigation water under alternative policies is similar to land use. Ground water is assumed to be available at $22.50 per acre-foot and project water will cost about $13.00. The quality standard does not substantially affect the total amount of water use but does reduce the use of ground water drastically. If ground water use decreases, as projected in this analysis, pumping costs may sufficiently decrease to the point where substantial amounts could again be economically utilized. Increased usage, however, depends on there being no serious decrease in water quality.

Cost of Achieving Alternative Levels of Water Quality

The total cost of alternative levels of nitrogen in receiving waters will be equal to the aggregate of the social damages caused by the disposal of drainage effluent plus the costs to farmers of reducing the nitrogen content in drainage water.

Costs of Nitrogen Abatement

The cost of achieving lower levels of nitrogen in drainage water was estimated by decreasing the NO_3-N effluent charge to obtain 5, 10, and 15 ppm concentrations. These costs were determined from the differences in net farm income. The incomes, costs and effluent charges are presented in Table 16. The total cost to the study area to achieve a 15 ppm level was $362,404. An average effluent charge of $0.14 per pound of nitrogen was required to achieve this level. Decreases in income due to reduced cotton acreages (12,000 acres in 2011+ time period) accounted for most of this cost. In addition, sugar

TABLE 16. Estimated Costs of Achieving Alternative Levels of Water Quality

Average annual district values*						
Drainage water		Total income	Total cost	Average cost TC/PPM	Marginal cost	NO_3-N effluent charge per lb.
NO_3-N concentration	Flow (AF)					
ppm		1,000 dollars				dollars
20.7	55,886	40,631	--	--	--	--
15.0	49,117	40,268	362	63.6	63.6	.14
10.0	40,897	40,216	415	38.8	10.5	.19
5.0	35,052	40,148	482	30.7	13.4	.24
2.0	32,451	40,089	542	29.0	20.0	.42

* See Appendix C for concentrations, flows and incomes by time period.

beets were replaced by alfalfa seed on about 25,000 acres of drained land. This change in cropping pattern does not represent a drastic decrease in net returns but does reduce the nitrogen content of the drainage water substantially. The reduction of NO_3-N levels from 10 to 2 ppm was attained by replacing crops using higher rates of nitrogen fertilizer with those using lower rates of nitrogen fertilizer rather than by substantially reducing crop acreages.

Crops fertilized with less nitrogen than required for maximum yields did not appear in the optimal solution to achieve any of the quality standards. This implies that a nitrogen water quality standard on drainage water can be achieved at lower cost by changing cropping patterns and land use rather than by decreasing nitrogen fertilizer rates on existing cropping patterns. However, as better soil classes begin to have higher water tables, reduced fertilizer rates on high value crops may be an optimal strategy.

The average and marginal costs were included in Table 18 to provide additional information on the shape of the total cost function. The total cost function for nitrogen abatement exhibits the expected increasing characteristics as higher levels of water quality are approached. The marginal cost function would be expected to increase sharply for nitrogen concentration rates lower than 2 ppm.

The Damages of Nitrogen Pollution

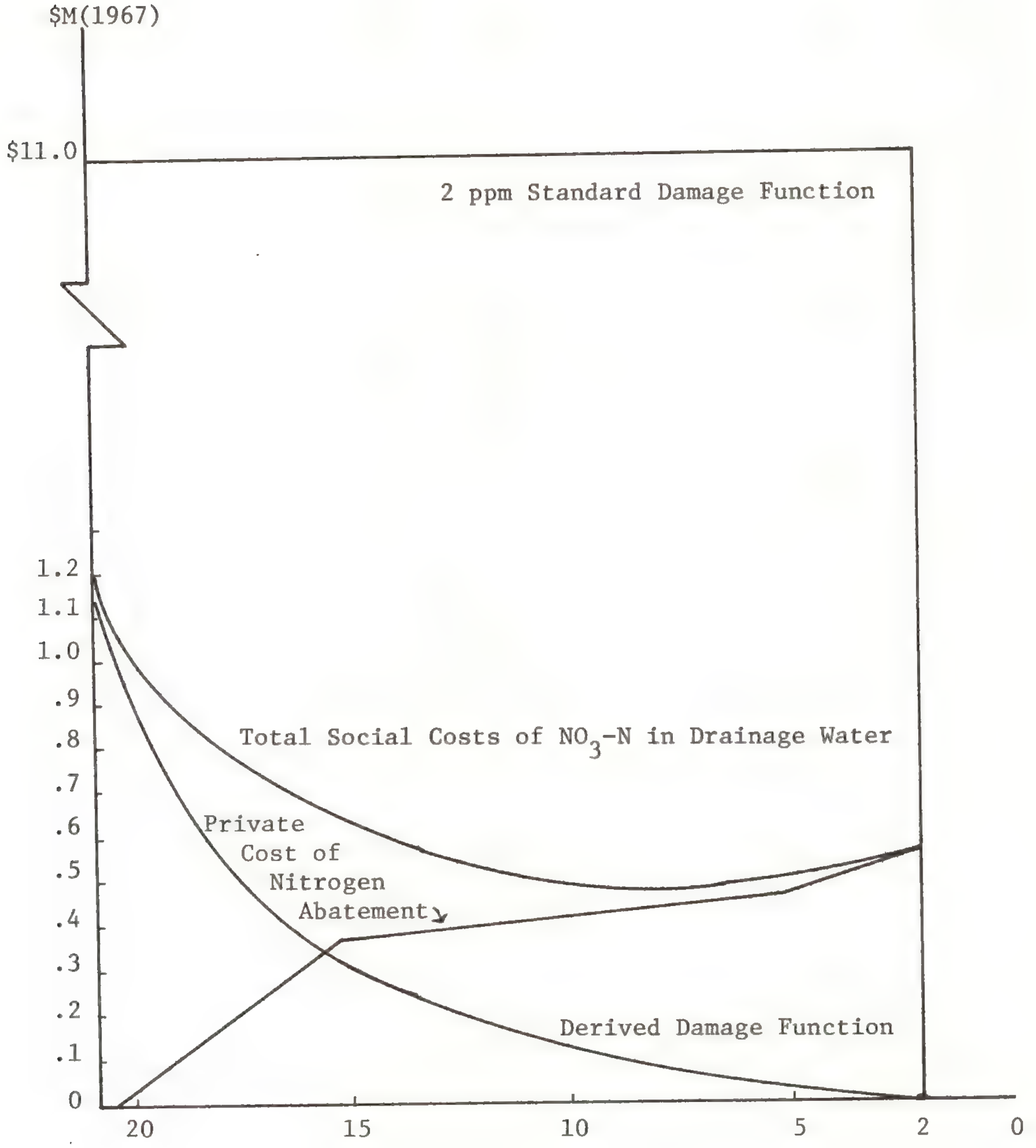
As stated previously, a standard serves as a substitute or proxy for a damage function. The FWPCA estimated the damages from the annual disposal of 500,000 acre-feet of drainage water at $11 million (U.S. Dept. of the Interior, pp. 5 and 12) The EPA has specified a 2 ppm NO_3-N limit on drainage water with no provisions for increasing the standard in the event smaller amounts of drainage water occurred. The damage function implied by the standard is plotted against concentration and cost in Figure 7. The function is vertical from 2 ppm to \$11 million and horizontal for concentrations greater than 2 ppm.[19/] This implies that drainage water with 2 ppm of NO_3-N or less would cause no damage whereas concentrations greater than 2 ppm will cause \$11 million of damage.

The estimation of a damage function to downstream users is beyond the scope of this study. However, to illustrate the importance of a damage function in the determination of least cost standards, a "crude" damage function was derived from the FWPCA damage estimates as follows. It is important to remember that the derived damage function is not meant to closely approximate the true damage function.

The \$11 million damages were estimated by EPA for the disposal of 500,000 acre-feet of drainage water containing 21 ppm of nitrogen. However, results from this analysis indicate that an optimal cropping pattern, without a constraint on the nitrogen concentration in the drainage, produces annually an average of 56,000 acre-feet of drainage water with 20.7 ppm of nitrogen (Table 16). The determination of the damage reduction from the reduced flow would be difficult and would depend on the factors considered, some of which would vary in magnitude or importance over time. Controversy exists within regulatory agencies over whether the concentration or the mass of the effluent discharges is more important in defining water quality standards. For simplicity, let us assume the damages are directly proportional to the flow if the N

[19/] See Central Pacific Basins Comprehensive Water Pollution Control Project, pp. 76-82. Damage estimates include decreases in shoreline property values, increases in boat hull maintenance costs, time and travel costs of substitute recreation experience and decline in the value of hunting.

FIGURE 7. Damage Functions, Private Cost of NO_3-N Abatement and Total Social Costs of NO_3-N in Drainage Water



ppm of NO_3-N in Drainage Water

concentrations are equal. About \$1.2 million in damages would result at the lower annual flow.[20] The other damage function reference point is zero damages at 2 ppm.

The assumed functional relationship between the amount of damages and the variation in the concentration of nitrogen is plotted in Figure 7 as a hypothetical damage function. The function is hypothesized to be convex to the origin rather than being linear for two reasons. First, when high nitrogen concentrations are experienced (21-18 ppm), the marginal damage reduction by decreasing the nitrogen concentration by some small amount may be quite high. However, at low nitrogen concentrations (5-2 ppm), the reduction in damages may be small for further reductions in the nitrogen concentrations. Barkley and Seckler (pp. 102-105) conceptualize a similar type of function stating that "... beneifts attached to efforts to clean up an already clean stream will certainly be very low, while even modest efforts to clean up a badly polluted stream may yield very high benefits."

The second reason to hypothesize a convex damage function relates to the concentration-mass argument discussed above to this example in particular. The damage function in Figure 7 does not account for changes in flow -- only for variations in nitrogen concentration. However, the optimal cropping pattern for decreasing nitrogen concentrations also results in decreased drainage flows (Table 16). Therefore, the reduced damages resulting from decreases in concentration would be even less if the flow were also reduced. The derived damage function shown in Figure 7 will be used to illustrate the determination of least cost standards.

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[20] $\frac{56{,}000 \text{ acre feet}}{500{,}000 \text{ acre feet}} \times \$11 \text{ million} = \$1.2 \text{ million}.$

The minimum total cost occurs where the slope of the two cost components are equal and their signs are opposite. In this example, the minimum cost is approached at about the 5 ppm concentration. In other words, the least cost standard of nitrogen in drainage water is 5 ppm achieved by an effluent charge of $0.24 per pound of NO_3-N (Table 16).

The marginal conditions for a minimum cost solution are also achieved. That is, if a 5 ppm standard is specified, the marginal damages of nitrogen pollution equal the marginal costs of nitrogen abatement. Therefore, the importance of the magnitude and nature of the damage function in determining a least cost standard of water quality is obvious and worthy of future research efforts. The assumption that no pollution and no damages (i.e., zero discharge) is the optimal situation for society is hard to justify on economic efficiency and welfare grounds. Granted, in this example, while a reduction of the standard or desired level of drainage water quality from 2 ppm to 5 ppm is probably negligible, the possibility of a damage function more convex to the origin certainly exists.

Conclusions

The least cost method of achieving the 2 ppm NO_3-N standard on subsurface drainage water is a tax or charge on the amount of NO_3-N in drainage water. The NO_3-N charge system was compared with costs (annual amortization, upkeep, and operating) of constructing a nitrogen removal treatment plant and allocating the costs of treatment to either the public sector, as one alternative, or to the farmers in the irrigation district, the other alternative.

The cost of the NO_3-N charge system is 34.3 percent of the cost of allocating treatment costs to farmers and 28.2 percent of the cost of allocating treatment costs to the public sector. Substantial differences in farm incomes, commodity production and resource use result from shifting the costs of nitrogen removal to the public sector from the farmers. Farmers lose incentive to use cultural practices and crop selection to reduce nitrogen in drainage water if the responsibility for achieving the standard belongs to the public sector. Farmers will produce the most profitable crops at levels which also produce substantial amounts of drainage water with high nitrogen concentrations. However, the public sector will receive some benefits from this policy. About 25,740 acres of field crops will be produced under the plan to allocate the costs to the public sector that would not be produced under the least cost NO_3-N charge plan. The loss of income to producers is $450,954.

The least cost alternative reduced land use from 386,000 to 360,000 acres, or 26,000 acres. This reduction in land use can be attributed to the imposition of the drainage water quality standard. Substantial increases in the acreage of land left idle would also result from high water tables. High water tables require the installation of subsurface tile which would require the promise of reasonably high returns. The area which will require drainage is also fairly low in agricultural productivity. Even with no standard on drainage water quality, about 167,000 acres will probably be left idle because the cost of drainage cannot be covered by net returns.

The damage caused by nitrogen in drainage water is important in determining a least cost standard. The total cost of a water quality constraint is the sum of the social damages of disposal plus the cost of pollution abatement. The least cost standard is that standard where the sum of these two cost components is minimized. Determination of the least cost standard is very sensitive to variations in the magnitude and functional relationship of social damages and water quality. This study was limited to estimating the costs of removing nitrogen from drainage water and did not address the social damages of nitrogen pollution. But estimation of that damage function would be required to determine the least cost drainage water nitrogen concentration standard.

Suggestions for Further Research

The policy implications of this research can be useful in its present form. However, the analysis could be improved by developing more sophisticated techniques for specifying the technical relationships between agricultural production practices (i.e., nitrogen fertilizer rates, methods and timing of nitrogen application, irrigation practices, tillage systems, plant spacing) and the nitrogen in drainage water. A systematic analysis incorporating economic models of agricultural production and simulation models of soil and water systems could be used to evaluate the economic impacts and environmental consequences of alternative water resource development, land use, and proposed environmental policies.

This analysis has also assumed that transactions costs are equal for the alternative policies considered, where transactions costs are defined as the implementation, enforcement and information gathering costs of a specific policy. It is possible that the transactions costs for any alternative policy will exceed the net social benefit of the nitrogen pollution control it provides. Therefore, a comparison of costs of alternative policies should include an approximation of transactions costs.

Institutions presently responsible for the environment have generally favored the use of effluent standards and enforcement to improve air and water quality. This institutional attitude is not conducive to the analysis or adaptation of effluent charge systems in accomplishing environmental goals. Reasons for this oversight and suggestions for the reorganization and consolidation of air, water, and land resources could be provided by research. Providing responsive institutions with analyses of environmental policies and resource management programs in addition to analyses of institutional alternatives is necessary and urgently needed for more rational decisions.

APPENDIX A

Table A-1. Per Acre Crop Yields by Soil Type and Rate of Nitrogen Fertilizer Application

Crop	Lb. of nitrogen	Unit	Yield per acre by soil type					
			A	A+B	B	C	C+D	D
Sugar beets	0	ton		18			16.2	
	50	"		22			19.8	
	100	"		24.5			22	
	150	"		26.5			23.85	
Alfalfa seed	0	lb.		600		540		
Cotton	0	lb.		850		765		
	100	"		1200		1080		
	115	"		1375		1238		
Dry beans	0	ton	1.157					
	40	"	1.356					
	80	"	1.500					
	120	"	1.547					
Wheat	0	ton		0.843				
	35	"		1.350				
	70	"		1.685				
	105	"		1.750				
	120	"		2.000				
Milo	0	ton		1.270				
	60	"		1.650				
	120	"		2.357				
	150	"		2.500				
Barley	70	ton		1.97		1.77	—	
	80	"		2.00		1.80	1.50	
	105	"		2.05		1.85	1.53	
Tomatoes	20	ton	22.8		20.5			
	70	"	25.3		22.8			
	120	"	26.0		23.4			
Cantaloupes, spring	0	ton	9.0		8.1			
	60	"	10.3		9.3			
	120	"	11.5		10.4			
	166	"	12.0		10.8			
Cantaloupes, fall	0	ton	8.1		7.29			
	60	"	9.27		8.37			
	120	"	10.35		9.36			
	166	"	10.8		9.72			
Potatoes, spring	60	cwt.	219		197			
	120	"	250		225			
Potatoes, fall	60	cwt.	197		177.3			
	120	"	225		202.5			
Sweet corn, spring	0	cwt.	11		9.9			
	100	"	95		85.5			
	200	"	120		108			
Sweet corn, fall	0	cwt.	24		21.6			
	100	"	79		71.7			
	200	"	90		81.0			
Oranges, navel (established)	150	cwt.	250					
Olives (established)	40	ton	5.0					
Peaches, clingstone (established)	100	ton	18.0					

--Continued on next page.

Table A-1. Continued

Crop	Lb. of nitrogen	Unit	Yield per acre by soil type					
			A	A+B	B	C	C+D	D
Peaches, freestone (established)		ton	5.0					
Nectarines	100	ton	8.0					
Plums (established)		ton	60.0					
Almonds (in shell)	150	ton	1.40					
Grapes	40	ton	9.0					

Source: Ibach, D.B., and J.R. Adams, Crop Yield Response to Fertilizer in the United States, Statistical Bulletin 431, Economic Research Service and Statistical Reporting Service, USDA, GPO, Washington, D.C., August 1968, pp. 31-35.

Isyar, Yuksel, The Potential Agricultural Development of the West Side of the San Joaquin Valley, California. Unpublished Ph.D. dissertation, Department of Agricultural Economics, University of California, Davis, June 1969, pp. 105-106.

Lingle, J.C., and J.R. Wright, Cantaloupes, Yield, Fruit Quality, and Leaf Analysis as Affected by Nitrogen and Phosphate Fertilization, Vegetable Crops Series 110, University of California, Davis, 1960.

Lorenz, et al., Fertility Experiments with Potatoes in Southern California, California Agricultural Experiment Station Bulletin 781, August 1961.

Tyler, et al., Sweet Corn Fertility Experiments, California Agricultural Experiment Station Bulletin 808, December 1964.

Table A-2. Fruits, Nuts, and Vines: Yields Selected for Analysis in Westlands Water District

Crop	Unit	Year												Life
		3	4	5	6	7	8	9	10	11	12	13	14+	(yrs.)
Oranges, navel	cwt.	--	12.5	75.0	137.5	180.0	210.0	230.0	240.0	245.0	250.0	250.0	250.0	40
Olives	ton	--	0.5	1.0	2.0	3.0	3.6	4.1	4.5	4.8	5.0	4.0	4.0	50
Peaches, clingstone	ton	--	4.0	8.9	13.0	15.0	17.0	18.0	18.0	18.0	18.0	18.0	18.0	20
Peaches, freestone a/	ton	--	--	1.0	3.0	6.0	7.5	8.5	9.0	9.0	9.0	9.0	9.0	20
Nectarines[b/]	ton	--	--	1.0	3.0	6.0	7.5	8.0	8.0	8.0	8.0	8.0	8.0	25
Plums[b/]	ton	--	--	0.66	2.2	4.0	5.0	5.7	6.0	6.0	6.0	6.0	6.0	35
Almonds (in shell)	ton	--	0.16	0.32	0.65	0.86	1.03	1.14	1.19	1.30	1.40	1.40	1.40	35
Grapes, wine	ton	3.0	6.0	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	35

a/ Salable fruit is 75 percent of yields shown.

b/ Salable fruit is 90 percent of yields shown.

Source: Isyar, Yuksel, The potential Agricultural Development of the West Side of the San Joaquin Valley, California. Unpublished Ph.D. dissertation, Department of Agricultural Economics, University of California, Davis, June 1969, p. 107.

APPENDIX B

TABLE B-1. Annual Drained Land Acreage, Nitrogen Use, Drainage Water, NO_3-N in Drainage Water, With and Without Standard, by Time Period

Time period	District values	Unit	Without standard	With standard	
				NO_3-N charge alternative	Treatment alternative
VI	Drained land	acres	67,947	54,569	62,490
	Nitrogen use	per acre	40.14	9.75	21.00
	Drainage water	acre-feet	45,284	30,192	38,974
	NO_3-N concentration	ppm	14.4	2.0	9.5
VII	Drained land	acres	82,404	52,675	71,687
	Nitrogen use	per acre	52.28	0.0	29.4
	Drainage water	acre-feet	54,227	30,025	43,673
	NO_3-N concentration	ppm	20.6	2.0	14.55
VIII	Drained land	acres	88,904	59,137	83,028
	Nitrogen use	per acre	59.57	2.9	33.6
	Drainage water	acre-feet	59,300	34,206	52,406
	NO_3-N concentration	ppm	22.8	2.0	19.42

APPENDIX C

TABLE C-1. Model Cropping Pattern for the Westlands Water District Without a Standard on Subsurface Drainage Water, Time Period VI, 1991-2000

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
	(Acres)							
Sugar Beets	44,047							44,047
Alfalfa	513			7,616	49,500			57,629
Cotton	10,157	158,043						168,200
Wheat-Drybeans			6,575					13,150
Wheat-Milo			4,257					8,514
Barley								0
Total Field Crops	54,717	158,043	10,832	7,616	49,500			291,540
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	36,574							36,574
Total Vegetables	44,850							46,799
Oranges	20,384							20,384
Olives	2,388							2,388
Deciduous	22,655							22,655
Tree Nuts	21,373							21,373
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	81,902							81,902
Total Land Use	181,469	158,043	10,832	7,616	49,500	0	0	
Total Land Available	181,469	158,043	11,557	10,055	49,500	75,168	66,690	

TABLE C-2. Model Cropping Pattern for the Westlands Water District Without a Standard on Subsurface Drainage Water, Time Period VII, 2001-2010

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
			(Acres)					
Sugar Beets	25,847				18,200			44,047
Alfalfa				26,329	31,300			57,629
Cotton	27,399	140,801						168,200
Wheat-Drybeans			6,575					13,150
Wheat-Milo								
Barley								
Total Field Crops	53,246	140,801	6,575	26,329	49,500			283,026
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	18,287							36,574
Total Vegetables	26,563							46,799
Oranges	20,384							20,384
Olives	2,388							2,288
Deciduous	22,655							22,655
Tree Nuts	21,373							21,373
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	81,902				49,500			81,902
Total Land Use	161,711	140,801	6,575	26,329	49,500	0	0	
Total Land Available	161,711	140,801	31,315	27,327	49,500	75,168	66,690	

TABLE C-3. Model Cropping Pattern for the Westlands Water District Without a Standard on Subsurface Drainage Water, Time Period VIII, 2011+

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
			(Acres)					
Sugar Beets		19,257		24,790				44.047
Alfalfa				8,129	49,500			57,629
Cotton	45,539	115,925						161,491
Wheat-Drybeans			6,575					13,150
Wheat-Milo								
Barley								
Total Field Crops	45,539	135,209	6,575	32,919	49,500			276,317
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	18,287							36,574
Total Vegetables	26,563							46,799
Oranges	20,384							20,384
Olives	2,388							2,388
Deciduous	22,655							22,655
Tree Nuts	22,672							22,672
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	83,201							83,201
Total Land Use	155,303	135,209	6,575	32,919	49,500	0	0	
Total Land Available	155,303	135,209	37,723	32,919	49,500	75,168	66,690	

TABLE C-4. Model Cropping Pattern for the Westlands Water District Without a Standard on Subsurface Drainage and Using a NO_3-N Charge Alternative, Time Period VI, 1991-2000

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
			(Acres)					
Sugar Beets	44,047							44,047
Alfalfa		8,129			49,500			57,629
Cotton	4,095	149,914						154,009
Wheat-Drybeans	6,575							13,150
Wheat-Milo								0
Barley			5,070					5,070
Total Field Crop	54,717	158,043	5,070		49,500			273,905
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	36,574							36,574
Total Vegetables	44,850							46,799
Oranges	20,384							20,384
Olives	2,388							2,388
Deciduous	22,655							22,655
Tree Nuts	21,373							21,373
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	81,902							81,902
Total Land Use	181,469	158,043	5,070	0	49,500	0	0	
Total Land Available	181,469	158,043	11,557	10,055	49,500	75,168	66,690	

TABLE C-5. Model Cropping Pattern for the Westlands Water District Without a Standard or Subsurface Drainage and Using a NO_3-N Charge Alternative, Time Period VII, 2001-2010

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
	(Acres)							
Sugar Beets		44.047						44,047
Alfalfa		4,954		3,175	49,500			57,629
Cotton	46,671	91,800						138,471
Wheat-Drybeans	6,575							13,150
Wheat-Milo								0
Barley								0
Total Field Crops	53,246	140,801		3,175	49,500			253,297
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	18,287							36,574
Total Vegetables	26,563							46,799
Oranges	20,384							20,384
Olives	2,388							2,388
Deciduous	22,655							22,655
Tree Nuts	21,373							21,373
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	81,902							81,902
Total Land Use	161,711	140,801	0	3,175	49,500	0	0	
Total Land Available	161,711	140,801	31,315	27,327	49,500	75,168	66,690	

TABLE C-6. Model Cropping Pattern for the Westlands Water District Without a Standard on Subsurface Drainage and Using a NO_3-N Charge Alternative, Time Period VIII, 2011+

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
	(Acres)							
Sugar Beets		44,047						44,047
Alfalfa				1,048	49,500	7,081		57,629
Cotton	38,964	91,162		1,511				131,638
Wheat-Drybeans	6,575							13,150
Wheat-Milo								
Barley								
Total Field Crops	43,590	135,209		2,559	49,500	7,081		246,463
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	18,287							36,574
Total Vegetables	26,563							46,799
Oranges	20,384							20,384
Olives	2,388							2,388
Deciduous	22,655							22,655
Tree Nuts	22,672							22,672
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	83,201							83,201
Total Land Use	155,303	135,209	0	2,559	49,500	7,081		
Total Land Available	155,303	135,209	37,723	32,919	49,500	75,168	66,690	

TABLE C-7. Model Cropping Pattern for the Westlands Water District With a Standard on Subsurface Drainage and Using a Treatment Plant, Time Period VI, 1991-2000

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
	(Acres)							
Sugar Beets	44,047							44,047
Alfalfa				8,129	49,500			57,629
Cotton	4,752	158,043						162,795
Wheat-Drybeans	6,575							13,150
Wheat-Milo			4,861					9,722
Barley								0
Total Field Crops	55,374	158,043	4,861	8,129	49,500			287,343
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	36,574							36,574
Total Vegetable	44,850							46,799
Oranges	20,384							20,384
Olives	2,388							2,388
Deciduous	22,655							22,655
Tree Nuts	20,716							20,716
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	81,245							81,245
Total Land Use	181,469	158,043	4,861	8,129	49,500	0	0	
Total Land Available	181,469	158,043	11,557	10,055	49,500	75,168	66,690	

TABLE C-8. Model Cropping Pattern for the Westlands Water District With a Standard on Subsurface Drainage and Using a Treatment Plant, Time Period VII, 2001-2010

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
	(Acres)							
Sugar Beets	29,989			14,058				44,047
Alfalfa				8,129	49,500			57,629
Cotton	16,682	140,801						157,482
Wheat-Drybeans	6,575							13,150
Wheat-Milo								
Barley								
Total Field Crops	53,246	140,801	0	22,187	49,500	0	0	272,308
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	18,287							36,574
Total Vegetables	26,563							46,799
Oranges	20,384							20,384
Olives	2,388							2,388
Deciduous	22,655							22,655
Tree Nuts	21,373							21,373
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	81,902							81,902
Total Land Use	161,711	140,801	0	22,187	49,500	0	0	
Total Land Available	161,711	140,801	31,315	27,327	49,500	75,168	66,690	

TABLE C-9. Model Cropping Pattern for the Westlands Water District With a Standard on Subsurface Drainage and Using a Treatment Plant, Time Period VIII, 2011+

	Soil Type							Total Acres of Crop
	Not Drained		Drained					
Crop	A	B	A Panoche	B Panoche	B	C	D	
			(Acres)					
Sugar Beets		18,648		25,399				44,047
Alfalfa				7,519	49,500	609		57,629
Cotton	38,964	116,561						155,525
Wheat-Drybeans	6,575							13,150
Wheat-Milo	0							0
Barley	0							0
Total Field Crops	45,539	135,209	0	32,918	49,500	609		270,351
Tomatoes	6,327							6,327
Cantaloupes	1,949							3,898
Other Vegetables	18,287							36,574
Total Vegetables	26,563							46,799
Oranges	20,384							20,384
Olives	2,388							2,388
Deciduous	22,655							22,655
Tree Nuts	22,672							22,672
Grapes	15,102							15,102
Total Fruits, Nuts, & Grapes	83,201							83,201
Total Land Use	155,303	135,209	0	32,919	49,500	609	0	
Total Land Available	155,303	135,209	37,723	32,919	49,500	75,168	66,690	

TABLE C-10. Annual Water Use With and Without Water Standard, by Time Period

Time period	Water source	Without standard	With standard	
			NO_3-N charge alternative	Treatment alternative
		acre-feet		
VI	Project	1,091,000	1,091,000	1,091,000
	Ground	113,907	74,409	97,221
	Total	1,204,907	1,165,409	1,188,221
VII	Project	1,090,000	1,090,000	1,090,000
	Ground	102,451	15,562	68,478
	Total	1,192,451	1,105,562	1,158,478
VIII	Project	1,090,000	1,090,000	1,090,000
	Ground	85,081	1,185	66,980
	Total	1,175,081	1,091,185	1,156,980

APPENDIX D

TABLE D-1. Annual Income, Drainage Water and NO_3-N Charge, by Alternative Standards and Time Period

Time Period	District Values	Unit	NO_3-N concentration in drainage water			
			2 ppm	5	10	15
VI	Annual income	$100,000	29.78	29.80	30.14	30.24
	Drainage water	1,000 ac. ft.	30.19	33.36	39.09	45.01
	NO_3-N charge	dollars	.47	.42	.19	.02
VII	Annual income	$100,000	41.81	41.88	41.88	42.05
	Drainage water	1,000 ac. ft.	30.03	33.17	39.64	51.39
	NO_3-N charge	dollars	.41	.22	.22	.11
VIII	Annual income	$100,000	42.95	43.02	43.02	43.02
	Drainage water	1,000 ac. ft.	34.21	36.24	41.92	49.73
	NO_3-N charge	dollars	.41	.19	.19	.19

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